NUCLEAR ENGINEERING

VOL. 1 NO. 4 JULY, 1956

PRINCIPAL CONTENTS

page

ECONOMICS OF ENRICHED FUEL REACTORS *by* **J. M. Kay**
L'Economie des Réacteurs d'Uranium Enrichi
Die Wirtshaftlichkeit der mit angereichertem Uran arbeitenden Kernkraftwerke
Lado Económico de los Reactores de Energía con Uranio enriquecido 141

THE DESIGNER AND RADIATION PROTECTION *by* **H. J. Dunster**
L'Ingénieur-Dessinateur et la Protection contre la Radiation
Der Konstruktör und der Schutz gegen Strahlen
El Proyectista y la Proteccion contra le Radiación 144

THE ARMY PACKAGE POWER REACTOR
Le Réacteur de puissance en paquet de l'Armée
Der Reaktor für den Tornister
Reactor de Energía de Tipo Militar 149

STATISTICS OF RADIATION MEASUREMENTS *by* **E. N. Shaw**
La Statistique des Mesures de Radiation
Die Statistik der Strahlungsmessungen
Estadisticas de Medida de Radiación 152

MECHANICAL CONTACTORS FOR LIQUID-LIQUID EXTRACTION *by* **J. D. Thornton**
Les Contacteurs mécaniques à grand Rendement pour les Opérations Liquide-Liquide
Hochwirksame mechanische Kontakteinrichtungen für flüssig-flüssig Extraktionsprozesse
Contactores de alta Eficiencia para Procesos de Extracción del tipo Líquido-Líquido . . 156

HARWELL OPEN DAYS
Journée Publique à Harwell
Besichtigungstage in Harwell
Dia de Visita en Harwell 160

ZIRCONIUM: PART 3—PROPERTIES AND USES *by* **G. L. Miller**
Zirconium: 3ème Partie—Propriétés et Emplois
Zirkonium: Teil III—Eigenschaften und Verwendung
Zirconio: Parte III—Propiedades y Usos 164

REGULAR FEATURES

EDITORIALS 137
COMMENTS ON THE NEWS . . 139
WORLD NEWS 169
TRADE NOTES 171
PERSONAL 172
TECHNICAL PAPERS 173
PROCESSES AND EQUIPMENT . 177
PATENTS REVIEWED . . . 178

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Chairman and Managing Director:
ROLAND E. DANGERFIELD

Editorial Director:
A. P. CHALKLEY, B.Sc.(Eng.)

Editor:
E. N. SHAW, B.Sc.

Head Office:
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NUCLEAR POWER ENGINEERING

The illustration shows the operating mechanism designed to fulfil the conditions of moving the control rods of a thermal reactor.
It is driven by a synchronous control torque-motor through a 20 : 1 gear ratio on to an edge-wise wound cable drum, giving one slow "out" speed, two faster "in" speeds and holding the control rod in any required position. The speed of the rods to the "shut-off" condition is controlled by a permanent magnet current brake.

120 of these operating mechanisms are now being manufactured for the Atomic Energy Authority's Power Station at Calder Hall.

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NUCLEAR ENGINEERING VOL. I NO. 4 JULY, 1956

EDITORIALS

Japan Favours Calder Hall Type

THE chairman of the Atomic Energy Commission in Japan, Mr. Matsutaro Shoriki has been reported as stating that Japan would buy a nuclear power station from Britain and that in the near future, a survey team would come to Britain to discuss the project and to negotiate the agreement. Included in the preliminary reports were statements to the effect that Japan had been given to understand that no secrecy restrictions would be applied and that the plutonium converted in the reactor would be the property of Japan. In reply to questions Sir Edwin Plowden, chairman of the U.K. Atomic Energy Authority, has made the comment that if the news agency reports are correct there is some misunderstanding on the question of fissile material used in the reactors. Agreements already concluded by the U.K.A.E.A. (which so far have referred to research reactors), provide for reprocessing in this country of any fissile material supplied by the United Kingdom and the U.K. would have to ensure that the terms of any future agreements were not in conflict with the control provisions likely to be laid down by the International Agency agreed by the 12-nation conference in April. The agency is to be set up under the auspices of the United Nations and is to be discussed at a full assembly in September of this year.

It will be surprising if this matter develops into any serious controversy as Japan at present has no facilities for reprocessing fuel elements and is unlikely to be in a position to undertake this work for some years to come. Irradiated fuel elements will, therefore, in any case, have to be shipped out of the country and the weight of plutonium produced within the first five years will not represent a very considerable military potential when the development necessary for the production of weapons is taken into account. Even for a station with an installed capacity of 100 MW and a heat rating of 400 MW for an efficiency of 25%; at 80% load factor, the quantity of plutonium produced will amount to approximately 90 kilograms per year.

The significance of the insistence on the absence of secrecy clauses and the objection to American proposals on this score are difficult to understand unless they can be interpreted in terms of delivery times being affected by classification. It is improbable, if this were the case, that secrecy considerations should have been described as the sources of objection and not the long delay in fulfilling an order and one is led to assume that the United States has implied that in a plant installed by them parts of the system would remain classified and information concerning them would be withheld from the purchasers and the operators. Such a provision could not, of course, be accepted by a purchasing country, particularly Japan where public feeling on atomic energy is liable to run very high as evinced by the recent outcry against the American hydrogen bomb tests, and operating personnel must insist on complete understanding of the reactor and its components, and on complete details of its design.

Of much greater significance than either of these two points—ownership and classification, is the considered opinion that the graphite-moderated, gas-cooled pile is not only in a more highly developed state, but also is more economic in operation and is likely to remain so at least until the completion of the installation. The decision by the Japanese A.E.C. is the result of the first serious independent appraisal, from the economic point of view, of the various methods of power production and it is particularly gratifying that this first foreign order (or possible order) for a complete nuclear power station should come to Britain. Those who have doubted the wisdom of this country concentrating on the natural uranium reactor will draw solace from the outside opinion. It should be remembered, furthermore, that Japan is considered to be almost wholly in the sphere of American influence and has been subjected to a fair amount of political and commercial pressure from the United States for many years.

Presumably to counteract U.S. reaction to the decision Mr. Shoriki is reported as saying that Japan would be pleased to purchase American nuclear power stations when the security and fuel requirements have been relaxed and we suggest, more important, when the economics of their reactor systems have been improved and proved. An energetic counter to this statement must be expected.

It is interesting at this stage in developments to contemplate the probable line of progress in the United Kingdom, if in 1946 we had been in the same position as the United States with regard to enriched and separated fissile material and if we had had access in the following years to United States information. It is possible that the appeal of an enriched system would have had a greater influence on developments and that we should not have progressed so steadily in our power reactor development programme.

The recent change in attitude of the United States to the exchange of information we believe has been largely conditioned by the expected success of the Calder Hall type and by the reputed economics associated with the designs to be submitted by the four Consortia to the C.E.A. in the autumn of this year. It is too early to make any final analysis of the natural uranium reactor against the enriched reactor but certainly at this stage in development the course which, it must be admitted, was largely forced on the United Kingdom has been proved to be advantageous.

Atomic Energy Insurance

THE conclusions of the committee set up by the British Insurance Companies and Lloyd's are being considered by the individual companies in the British insurance market that would be concerned with the insurance of establishments working on atomic energy problems. In a provisional announcement the committee has stated that although possible radioactive contamination involving damage to plant and liability to third parties is a new risk other hazards are not significantly different from those encountered in many industrial processes and no difficulty is envisaged in covering even the largest plants for insurance purposes. At present the committee has been largely concerned with examining the hazards involved in gas-cooled, graphite-moderated power stations of the Calder Hall type, clearly with specific reference to the stations which will be under construction next year for the C.E.A.

Whilst the Atomic Energy Authority is directly Government controlled from the insurance aspect, coverage being obtained through the taxpayer, the C.E.A. is at present largely insured through insurance companies and a departure from this existing practice for the new nuclear power stations is not envisaged. In its deliberations the committee has of course been hampered by the difficulty of having no second authority to go to for advice. In the United Kingdom, although differences arise over almost all aspects of the nuclear power programme, the general trend of thought has been fostered and developed in one school only and the basic line of approach is therefore the same throughout the A.E.A. and industry. Nevertheless we understand that the committee feels that this problem is by no means insuperable as the experience of insurance companies in other fields of risk can be extrapolated to this new field with a reasonable degree of certainty.

Normally premium rates are fixed on previous experience, accurate statistics providing a firm basis for new quotations, but it will be many years before significant statistics are available for nuclear power stations. The willingness of British Insurance to cover these stations implies great confidence in the design although no doubt initial premiums will carry a fair margin for error. The reluctance of the United States companies to cover very large insured sums is partly conditioned by the more rigid Federal laws referring to insurance than by doubts in the atomic energy projects.

At present no reconsideration has been given to the insurance of individual persons working in the atomic energy field. This is in sharp contrast to the United States where only 0.3% of the 150,000 people employed in atomic energy plants carry an industrial hazard excess to their life insurance premiums. It is to be hoped that the lead that the United States has given with regard to personal insurance will soon be followed in this country where it is felt by many an excessive occupational hazard premium is imposed on workers in the atomic energy field, involving an increase of 10s. per cent of the insured sum, which may with single premiums come to as much as 120% of the normal premium. It is significant that whilst life insurances carry this considerable excess there is no equivalent deduction for deferred annuities, admittedly in the event of the death of the insured before maturity the premiums paid in are returned, but the early death of the insured person is to the advantage of the insurance company. An excess premium, therefore, on life insurance would logically be accompanied by decreased premiums on deferred annuities.

The time has come, however, when this matter should be of purely academic interest and personal excess premiums discontinued except for the most exceptional occupations which incur hazards from, say, machinery rather than radiation. There is now a very adequate quantity of statistical information available which will prove that the record of health in all branches of the atomic energy industry has been remarkably good and the regular medical attention that workers receive makes to an increase in the probable life of the employee. This matter is of less concern, no doubt, to the employees of the A.E.A. and companies who are prepared to pay the whole of the excess premiums incurred on insurances covering house property, etc., than for employees of smaller companies who are unable to provide these facilities.

An early reconsideration of the whole structure of the excess occupational hazard premiums as applied to persons in the atomic energy industry is most desirable.

The Press at Harwell

AFTER ten years of rather awesome mystery the gates of Harwell were opened to the Press during the week beginning May 28. In general the reaction of the lay Press has been one of profound disappointment. One photographer summed this up when he said that he had been waiting ten years to get into Harwell and now he had been he never wanted to go again. The great event has been allowed to pass, therefore, with little comment, but it is significant that the Atomic Energy Authority has recognized the curiosity with which atomic energy developments are viewed particularly when these developments have been shrouded in secrecy. It is probable that if this Press visit had occurred three years ago atomic energy would have hit the headlines rather less frequently in the past months than it has.

It must be remembered, however, that Harwell is essentially a research organization and that it is concerned entirely with matters highly technical in which the general public would have little interest and even less understanding. Furthermore, the dissemination of news requires a great deal of time and effort to organize. There have been a number of exhibitions both in this country and abroad where the A.E.A. has taken representative equipment and has been prepared to answer questions on most topics not connected with weapons with the rather peculiar exception of thermo-nuclear research. Admittedly it can be argued that this falls into the category of commercial security which on behalf of the taxpayer must, to a limited extent, be maintained. Whether it is applicable to this particular topic is questionable, but there are many facets of the practical developments of atomic energy which it would be unwise to disclose prematurely.

There are also many which it would be unkind to make public too early on. All experimental work, particularly in its initial stages, tends to be tentative and is always fraught with difficulties, and considerable embarrassment can result if premature reports indicate the imminent solution of a problem which is subsequently found to entail further lengthy research.

Finally there is the question of the value of promoting the release of information which, like prestige, is very difficult to correlate with the cost and effort involved; the aim must be to balance the two factors in the equation to give a maximum benefit to the industry as a whole, and to satisfy the public that developments affecting its future will be made known as soon as possible.

Comments on the News

NEW A.E.A. ESTABLISHMENT

There seems little doubt that the new testing station for the Atomic Energy Authority will be established in Dorset on Egdon Heath, Winfrith. Proposals to take over the site have now been submitted by the A.E.A. to the Dorset County Council. It is unlikely that the Council will raise any objections to the proposals, particularly—as some cynics have been heard to say—when the A.E.A. could overrule any such decisions through the Ministry. On the whole, however, responsible opinion in Dorset is in favour of the proposed site and is pleased that an industry will be established which can absorb some of the young technical effort that is available. It is understood that the establishment will recruit approximately 2,000 people from the surrounding area.

Originally a certain amount of apprehension arose over water requirements at the establishment and extensive tests were carried out by George Wimpey and Co. Ltd. to prove that site requirements, averaging 2½-3 million gallons a day and never peaking more than 10 million gallons a day, could be met by borings at West Stafford.

There has been some protest from "Hardy enthusiasts" over the despoiling of the countryside, but judging from the almost completely deserted nature of the heath at all seasons of the year, this cannot be taken too seriously. The area is particularly desolate and because of this much of the country surrounding has been in the hands of the Army for many years. The only section of the community that is liable to meet with difficulties is the farming section which is anticipating a loss of labour during construction.

RADIATION HAZARD REPORTS

The report of the Medical Research Council on the hazards to man of nuclear and allied radiations was put before Parliament on June 12. The same day a similar report was released in the United States. The two documents contain much the same information although the American is rather more comprehensive in scope. A careful analysis of the hazard is given with a discussion on the form of injury that is liable to occur with over exposure and the possibilities of genetic effects on the population as a whole. From the reports it can be clearly seen that the major sources of exposure of the population apart from cosmic radiation are the X-rays used in diagnostic and therapeutical work. Both reports call for a review and a curb on the indiscriminate use of X-rays in the medical field so that excessive exposure can be avoided. The most significant result of atomic energy developments is probable fall-out from hydrogen bomb experiments, but at the present time the level of strontium activity is insignificant and even if tests continue at the same rate no hazard is anticipated.

About the same time preliminary recommendations were released by the International Commission on Radiological Protection which met in Switzerland some time ago. The Commission has no executive powers but previous recommendations have always been adopted. The most significant point made was that although present maximum permissible levels for moderate periods of time should not be altered the total exposure received in a life-time should represent only a third of this as a mean rate. The commission recommends that the maximum accumulated dose for persons up to the age of thirty should be 5 r, up to forty 100 r and up to sixty 200 r.

EXPORT OF RESEARCH REACTOR

Included in the considerable reactor buying programme of Western Germany itemized in the news pages of this issue is a swimming pool reactor which has been ordered from A.E.I.-John Thompson Nuclear Energy Co. Ltd. It is understood that although this is still subject to the granting of fuel by either the U.K. or U.S. it is unlikely that there will be any hold-up in the contract. The type of fuel elements used in Merlin are manufactured both in the U.K. and the U.S. but it is probable that the reactor will be fuelled by elements made in this country.

A figure of £75,000 has been quoted as the purchase price and will include the reactor assembly (excluding fuel elements), control mechanisms and circuits, experimental facilities, etc., but will not include the civil engineering associated with the biological shield, and the laboratories—incidentally, two "big names" in their field, Balfour, Beatty and Co. Ltd., and John Laing and Son Ltd. are now associated with the company as civil engineering contractors. A delivery time of one year has been given and it is possible that, if work on the construction of the A.E.I. reactor is delayed for any length of time, the German model will be in operation first.

We understand that the company has received a number of inquiries from other sources for this type of reactor and that several overseas countries are interested. The German reactor will be identical with Merlin in all but certain details of the experimental facilities, but the company is envisaging the production of reactors with different core characteristics —such as invested reactivity.

NUCLEAR-PROPELLED TRAINS

The development of nuclear-propelled locomotives is probably of less interest to the inhabitants of the United Kingdom than most countries with highly developed railroad systems as density of population and frequency of train services (and, therefore, accidents in populated areas) call for an exceptional accent to be placed on safety considerations. Furthermore, a considerable section of the system in Southern England is already electrified and plans are in hand for the extension of this. Large quantities of electricity available at cheap rates will enable many of the main lines to be electrified economically within the next few decades.

The circumstances are not quite the same in the United States and the U.S.S.R. There have been reports from the Soviet Union that a nuclear-powered locomotive will shortly be on trial and the value of such a traction system can be appreciated, particularly on trans-Siberian runs where many thousands of miles of isolated country have to be traversed. In the United States the biggest suppliers of locomotives—General Motors Corporation—had anticipated that by about 1960 many of the diesel engines (comprising 95% of the traction power) would have been replaced by gas turbine units. The rather slow development of the gas turbine and its inherent poor economy at fractional load has extended the life of the diesel for another 15 years. The attitude of this company to nuclear power can best be summarized as a policy of "wait and see," in that present designs envisage basic chassis units which can carry turbine generators, diesel generators, and heat exchangers and nuclear power plants if these ever become economic. Whilst the company is assembling a team to devote its efforts to the development of economic nuclear power it should be remembered that it has a considerable interest in small stationary power units.

Leaving aside the attitude of the general public towards a nuclear-powered locomotive in the remoter parts of the United States where there are many hundreds of miles of railroad running through very sparsely populated country, nobody is prepared at the present stage to envisage the use of this type of traction in a densely populated area and the cost of changing engines at the outskirts of built-up areas would probably make the use of a nuclear-powered locomotive uneconomic, even if fuel costs over the greater proportion of the run were negligible.

Nevertheless, lower maintenance charges which might conceivably obtain with a highly developed reactor system and the steady increase in the quantity of oil imported into the United States may encourage the development of a nuclear-powered locomotive on an experimental basis, but many years of practical development are necessary before any real conclusions can be drawn on the economic value and strategic value of such a system.

ECONOMIC NUCLEAR POWER

A phrase that is in common usage today in atomic energy circles is "economic nuclear power", in general intending to convey the meaning that cost is comparable with that obtained from coal and oil. The real meaning of the term economic with reference to electric power is obscure as in a modern industrialized society electricity is an essential commodity almost regardless of price. There are few manufacturing processes where even doubling the cost of electricity would do more than increase the cost of the produced goods by a few per cent., and even for domestic usage the family bill rarely represents more than a few per cent. of the total income.

In the United Kingdom we must have electricity and our coal and oil reserves force us to turn to the new source of energy irrespective of its cost. Conversely in the completely undeveloped countries even where fuel, say, in the form of wood, is readily available there is no requirement as yet for electricity generation and, therefore, any cost of electricity producing plant is high. Only when we are attempting to sell a nuclear reactor system abroad does the word economic begin to take on a real significance.

This is not to say of course that the cost of generated electricity is of no interest, but to this country certainly its availability is of far greater concern, and although it would appear that we are in the fortunate position of being able to generate electricity from atomic energy at a cost less than that obtaining today from coal and oil it is much more significant to our future prosperity that the potential power available from uranium and thorium is almost unlimited.

EURATOM PROGRESS

Foreign ministers of "little Europe" representing France, Italy, Western Germany, Belgium, Holland and Luxembourg met in Venice on May 29 to discuss the experts' report on the atomic energy pool Euratom. Early agreement was reached on the next step but few important decisions were taken on controversial matters. It was agreed to draft two treaties which would cover the European atomic energy pool and the customs union independently. A conference was due to be called in Brussels on June 26 to discuss these draft treaties under the chairmanship of Monsieur Spaak, the Belgium foreign minister.

The main difficulties to be overcome are Franco-German disagreements on the status of Euratom relative to military developments and the strong French objection to the proposal by Belgium, Holland and Luxembourg that Euratom should be closely linked with the establishment of a single market. France is also insisting that dependent countries, such as her overseas territories, should be included in the six nation common market and Belgium also is likely to support this proposal. There is a considerable body of opinion in Europe attempting to influence Britain to join the scheme but at present no move has been made by the United Kingdom and the insistence on the integration of overseas territories is liable to raise further stumbling blocks.

The decision, however, to tackle the problem of a common market and atomic energy pool under two different charters will give a greater chance of success at least to the latter and the strong feeling that exists in Europe that co-operative action is the only answer to American competition lends a further impetus to the scheme.

GOVERNMENT v. INDUSTRY

There has been a growing feeling in the United States that the Government should take a greater responsibility for the development of reactors for nuclear power. The international competitive spirit appears to have been the chief driving force and a number of eminent men have called on the Government to initiate a large-scale power programme, apparently merely to make the U.S. atomic energy programme the biggest in the world.

During the debates on the atomic industry bill before Congress the full scale participation of the Government was strongly criticized by a number of industrial representatives who pointed out that a Government sponsored nuclear power programme could only duplicate work that was already in hand and would essentially trample on the precincts of private industry. There is a tendency in the United States to regard atomic energy as a major source of international prestige rather than electricity—oil is still plentiful and relatively cheap, but the interests of private industry are sufficiently strong for Government undertakings to be confined to research and development only, particularly that directly associated with military objectives as exemplified by the APPR, the atomic powered aeroplanes, and naval vessel nuclear propulsion projects.

THE SIXTH W.P.C.

The World Power Conference began its sixth convention in Vienna on June 18. In his presidential address Sir Harold Hartley, K.C.V.O., C.B.E., F.R.S., spoke of the importance of this conference to which more than 400 delegates had come from Britain alone. The harnessing of atomic energy had come, he said, at a most timely moment as much of our future progress was dependent upon the availability of large quantities of energy. He pointed out that food was the most urgent need of the world today and called for a greater apportioning of emphasis on power in agriculture.

The conference includes for the first time papers on atomic energy (see pages 174-176) including short reviews of the Calder Hall project and the Shipping Port and Commonwealth Edison Company reactors.

Although it is anticipated that in the United Kingdom, nuclear power generation will equal that from coal by 1975 other countries will be much slower in augmenting their present systems by atomic energy and it will be some years before this new source of power can make a firm impression upon the total world power production.

IT'S A WISE CHILD

One of the most controversial subjects in health circles today is long-term genetic effects of radiation. Research workers are considerably hampered by the absence of accurate family records and both recent British and American reports have called for this position to be rectified as speedily as possible. In attempting to trace back the ancestry of interesting cases considerable complications always arise and one M.R.C. spokesman has implied that the nursery picture of the gooseberry bush is a more accurate picture of modern society than the family tree.

The Economics of Enriched-Fuel Reactors

Estimates of costs show that enriched-fuel reactors based on the supply of material from diffusion plants do not appear so attractive as natural uranium reactors at comparable levels of irradiation. Using plutonium as enrichment and with appropriate re-cycling this type of reactor becomes more economic.

by

J. M. KAY, M.A., Ph.D., A.M.I.Mech.E.

THERE are only two practical types of nuclear reactor in which natural uranium may be used as the fuel—the graphite-moderated gas-cooled reactor and the heavy-water-moderated reactor. The graphite-moderated gas-cooled reactor has been chosen for the opening round of the power programme in the United Kingdom and the economics of this type of power plant were outlined in *Nuclear Engineering* for May. The alternative approach of using natural uranium in heavy-water-moderated reactors would probably result in the production of power at much the same cost as from graphite-moderated gas-cooled reactors provided the necessary heavy water could be manufactured at a price of not more than £30,000 per ton. The heavy capital outlay and energy consumption required for a large-scale heavy-water production plant, however, are such as to swing the balance in favour of the graphite-moderated gas-cooled reactor. Nevertheless the U.S. is prepared to sell a limited quantity of heavy water at $28 per pound, that is, £20,000 per ton.

Other types of nuclear reactor such as the pressurized light-water-moderated reactor, the boiling-water reactor, and the sodium-graphite reactor, require a supply of enriched uranium for their fuel. It is sometimes suggested that these liquid-cooled reactors are inherently superior to the gas-cooled type but, in fact, this is not necessarily the case and it is quite possible that the gas-cooled reactor may become established as the standard type of plant for large base-load power stations for many years to come. There will still be a strong incentive, however, to develop one or more of the possible types of liquid-cooled reactor for power production, and two reasons may be mentioned in particular. Liquid-cooled reactors, and especially the water-moderated reactors, are physically compact and thus do not involve such serious site constructional problems as the gas-cooled type, and this may be an important consideration for plants of only moderate power output. Further, the availability of by-product plutonium from the earlier graphite-moderated reactors will present an alternative method of providing enrichment and this can be put to the best advantage with one or other of the liquid-cooled reactors.

The simplest type of fuel cycle for a reactor using enriched uranium is shown in Fig. 1. Natural uranium is converted into UF_6 and fed to a diffusion plant. Enriched UF_6 from the top end of the plant is then converted into metal and used for the manufacture of fuel elements, whilst depleted UF_6 from the bottom end of the plant is rejected. Irradiated fuel from the reactor is passed to the chemical separation plant from which the by-product plutonium may be extracted. In the simplest or "single-pass" system the uranium from the chemical separation plant would be discarded but this would only be economically justifiable if the degree of enrichment of the fuel was small and the level of irradiation of the fuel very high.

In the following illustrative calculation we will consider the case of a hypothetical water-moderated reactor having a heat rating of 500 MW, an electrical output of 135 MW, and a fuel charge consisting of 50 tons of uranium enriched to 1.5 times the natural concentration. It would be reasonable to expect that the capital cost of a large nuclear plant of this type could be reduced to £100 per kW installed. The cost of the initial charge of fuel will be taken as the sum of the cost of 50 tons of natural uranium at £20,000 per ton plus the cost of enrichment in the form of additional U 235.

The lowest figure that can reasonably be assumed for the price of U 235 is the American quotation of $25 per gram, or approximately £9,000 per kilogram. How far this represents the actual cost of production from American diffusion plants, however, is open to speculation. It would probably be wise to regard this figure as representing the optimistic end of the bracket. At the pessimistic end the figure might be 50% greater.

The total capital cost of our hypothetical 135-MW reactor plant will be £13.5 million (excluding the initial charge of fuel). This will be divided into unconventional and conventional items in the ratio of 1:2. The fuel investment will be £2.6 million at the optimistic end of the scale. Annual capital charges may therefore be set out as follows:

£4.5 million at 4% and 15 years	405,000
£9.0 million at 4% and 30 years	520,000
	925,000
add interest on capital investment of fuel ...	104,000
Total annual capital charge	£1,029,000

With no re-cycling of uranium, the annual fuel requirement when operating at 80% load factor would vary with the average level of irradiation in the following way:—

Irradiation: MWD/ton ...	2,000	3,000	4,000	5,000
Annual throughput of fuel: tons	73.0	48.6	36.5	29.2
Cost: £ million	3.80	2.53	1.90	1.52

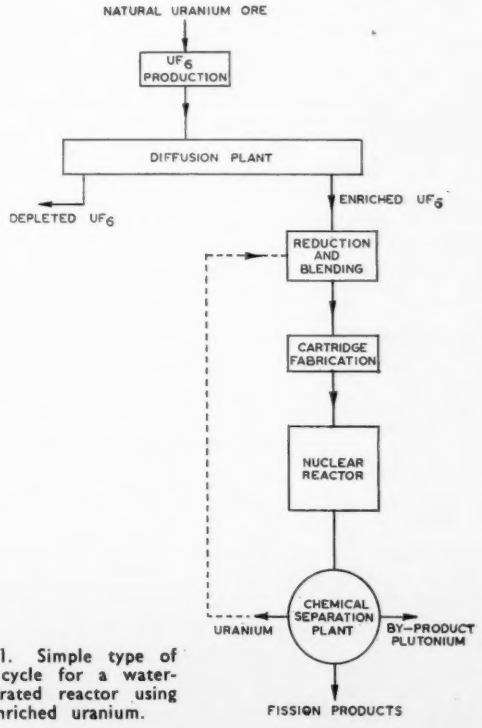

Fig. 1. Simple type of fuel cycle for a water-moderated reactor using enriched uranium.

the latter item being calculated on the basis of natural uranium fabricated into finished fuel elements at £20,000 per ton plus the necessary additional enrichment using U 235 at £9,000 per kilogram.

The gross cost of power from this reactor, when operating at 80% load factor, may now be set out as follows in pence per kWh:—

Irradiation MWD/ton ...	2,000	3,000	4,000	5,000
Capital charges	0.261	0.261	0.261	0.261
Fuel replacement ...	0.963	0.641	0.481	0.385
Operating costs	0.100	0.100	0.100	0.100
Total in pence per kWh	1.324	1.002	0.842	0.746

Even with an irradiation level of 5,000 MWD/ton, therefore, this reactor working on the single-pass system would not be competitive with a conventional coal or oil-fired station of similar size.

As in the case of the graphite-moderated gas-cooled reactor, however, some credit must be allowed for by-product plutonium. Taking an overall conversion factor of 0.70, the annual output of by-product plutonium when operating at 80% load factor would be 107.5 kg. With a selling price of £6,000 per kg the net annual fuel bill would thus be reduced by £645,000, and the net cost of generation in pence per kWh would be as follows:—

Irradiation MWD/ton ...	2,000	3,000	4,000	5,000
Cost in pence per kWh ...	1.160	0.838	0.678	0.582

and this would represent an economic source of power if an irradiation level of 5,000 MWD/ton could be achieved.

The reason for the relatively uneconomic nature of a plant of this type at lower levels of irradiation is mainly due to the fact that uranium is then being discharged from the system whilst still having a relatively high content of the fissile isotope U 235. As an illustration of this effect, it may be noted that fuel having an initial U 235 concentration 1.5 times that of natural uranium would be discharged after irradiation to a level of only 2,000 MWD/ton at a U 235 concentration 1.2 times that of natural uranium; that is, it would still be enriched material at discharge. The situation at the lower levels of irradiation may be improved by re-cycling the uranium from the chemical separation plant. This is represented by the dotted line in the flowsheet of Fig. 1. At the same time an appropriate adjustment must be made to the rate of feed and to the degree of enrichment of the material delivered by the diffusion plant.

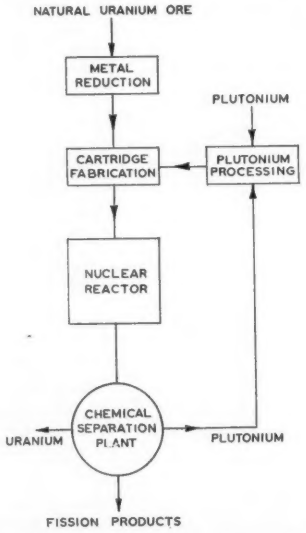

Fig. 2. Flowsheet for a reactor with re-cycled plutonium and with a fissile-material make-up of by-product plutonium from other reactors.

The cost of generation with re-cycling of uranium may be estimated by allowing a processing and fabrication charge of, say, £10,000 per ton of re-cycled fuel and by adding a make-up of U 235 from the diffusion plant at the previously quoted price of £9,000 per kilogram. The cost of power calculated on this basis for our hypothetical water-moderated reactor at 80% load factor, allowing the same credit for plutonium as in the last calculation, would be:—

Irradiation MWD/ton ...	2,000	3,000	4,000	5,000
Cost in pence per kWh	0.732	0.670	0.639	0.621

Whilst this would not be immediately competitive with a conventional coal or oil-fired station of similar size, the difference in cost is not very great and might well disappear within two or three years. The conclusion is that enriched-fuel reactors based on the supply of material from diffusion plants cannot be ruled out on economic grounds, although with comparable levels of irradiation they do not appear to be so attractive as natural uranium reactors.

The next step is to consider the use of plutonium as the source of enrichment. A flowsheet is shown in Fig. 2 for a reactor with re-cycled plutonium and with a fissile material make-up of by-product plutonium from other reactors. It is important to appreciate that the problems of handling and fabricating plutonium are very difficult. It is not yet clear whether it will be more convenient to mix the uranium and plutonium in the same fuel elements or whether it will be preferable to have two distinct sets of fuel elements, one consisting of natural uranium and the other of plutonium diluted or alloyed with some other material.

Taking the same hypothetical water-moderated reactor as before with a heat rating of 500 MW, an electrical power output of 135 MW, a load factor of 80%, and a plutonium conversion factor of 0.7, the cost of power may be calculated as follows:—

Irradiation MWD/ton ...	2,000	3,000	4,000	5,000
Cost in pence per kWh	1.079	0.759	0.597	0.501

In estimating these figures the natural uranium feed has been taken at £20,000 per ton and the plutonium make-up at £9,000 per kilogram. The last figure is greater than the £6,000 credit previously allowed for by-product plutonium to take account of the cost of processing and fabrication. It will be observed from this example that an enriched-fuel reactor using plutonium could be an economic proposition at an irradiation level of 4,000 MWD/ton and upwards.

At the lower levels of irradiation it will be worth while to re-cycle the uranium as well as the plutonium. Allowing a processing and fabrication charge of £10,000 per ton of re-cycled uranium as before and a cost of £9,000 per kilogram for the plutonium make-up, the cost of power may be estimated as follows:—

Irradiation MWD/ton ...	2,000	3,000	4,000	5,000
Cost in pence per kWh ...	0.652	0.590	0.559	0.541

The results of the last two sets of calculations for the plutonium enriched reactor are plotted in Fig. 3.

Once again it is necessary to emphasize that all these estimates are tentative and are liable to gross adjustment.

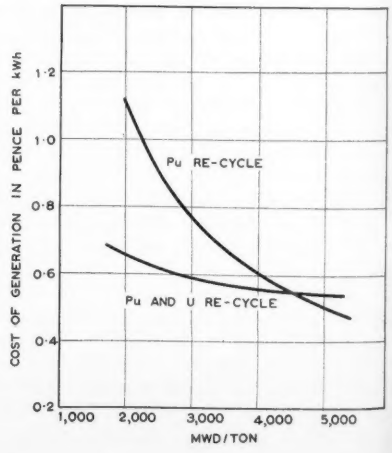

Fig. 3. Re-cycling the uranium as well as the plutonium is an economic proposition at the lower levels of irradiation.

L'Economie des Réacteurs d'Uranium Enrichi

Dans le numéro de Mai de "Nuclear Engineering" l'aspect économique du grand réacteur d'uranium naturel refroidi au gaz a été l'objet d'une discussion. Dans cet article, le même traitement est appliqué aux réacteurs enrichis avec une mention préliminaire des réacteurs thermiques, modérés par l'eau lourde. Le système hypothétique est pris comme exemple dans lequel le taux de chaleur est de 500 MW donnant un rendement électrique de 135 MW. Si on calcule sur la base de $25 le gramme pour l'U 235 et une dépense initiale pour le réacteur de 50 tonnes de £2.000 la tonne d'uranium naturel, et un placement de capital de £100 par kW installé, la dépense annuelle en capital sera légèrement au-dessus de £1.000.000.

Sans recyclage d'uranium, et en fonctionnant à un facteur de charge de 80%, les besoins annuels en combustible s'élèvent à £1,52 millions pour une période d'irradiation de 5.000 MW par tonne. Le coût minimum de l'électricité est sur cette base de 0,746 pence par kW/heure sans bonification pour le plutonium produit. En se basant sur des taux conservateurs de conversion et de valeur du plutonium, ce montant est réduit à 0,582 pence par kW/heure. Toutefois, le système d'un tel procédé de cycle unique entraîne des pertes et avec un recyclage approprié le coût pourra être réduit à 0,5 pence par kW/heure.

Die Wirtschaftlichkeit der mit angereichertem Uran arbeitenden Kernkraftwerke

Im Mai-Heft von "Nuclear Engineering" wurde die Wirtschaftlichkeit grosser gasgekühlter Reaktoren, die mit natürlichem Uran arbeiten, behandelt. In dem vorliegenden Artikel werden in der gleichen Weise die mit angereichertem Uran arbeitenden Reaktoren besprochen, wobei auch die Wärmereaktoren, die mit schwerem Wasser als Bremsstoff arbeiten, erwähnt werden. Es wird als Beispiel ein System angenommen, bei welchem die Wärmeerzeugung gleich 500 MW ist, was einer elektrischen Leistung von 135 MW entspricht. Wenn man 25 Doll./g für U 235 rechnet und die erste Füllung des Reaktors mit 50 t natürlichem Urans zu £2.000 die Tonne annimmt, wozu dann noch £100 pro KW als Kapital investiert werden müssten, dann ergibt sich eine jährliche Kapitalsbelastung von etwas über £1.000.000. Wenn das Uranium nicht in den Kreislauf zurückgeht, und wenn ein Belastungskoeffizient zon 80% eingesetzt wird, dann kommt man zu einem jährlichen Brennstoffverbrauch von £1.520.000 für eine Bestrahlungsdauer von 5.000 MW je Tonne. Auf dieser Basis kommt man schliesslich zu der Mindestsumme, die die Elektrizitäterzeugung kosten muss, nämlich 0,746 pence je kW-Stunde, jedoch ohne den Gewinn aus dem erzeugten Plutonium einzusetzen. Wenn man die Kosten der Umwandlung in Betracht zieht, und dann den Wert des Plutoniums berücksichtigt, dann reduzieren sich die Kosten auf 0,582 pence pro kW-Stunde. Das System mit einfachem Kreislauf ist an sich ein unwirtschaftliches Verfahren, mit mehrfachem Kreislauf kann man die Kosten auf 0,5 pence pro kW-Stunde reduzieren.

Lado Económico de los Reactores de Energía con Uranio Enriquecido

En el número de mayo de "Nuclear Engineering" se discutieron los problemas económicos de los reactores grandes de uranio natural enfriados a gas. En este artículo se aplica el mismo tratamiento a los reactores enriquecidos con un preámbulo sobre reactores térmicos, moderados por agua pesada. Se emplea el sistema hidpotético como ejemplo en el cual el régimen de calor es de 500 MW dando un rendimiento eléctrico de 135 MW. Tomando como base la cifra de $25—por gramo de U 235 y una carga incial del reactor de 50 toneladas a razón de £2.000—por tonelada de uranio natural y una inversión de capital de £100—por cada kW instalado, la carga total anual supera en algo al millon de libras esterlinas.

Sin reciclado de uranio y operando al 80% del factor carga las necesidades anuales de combustible se aproximan a £1,52 millones por un tiempo de irradiación de 5.000 MW por tonelada. El costo mínimo de electricidad sale sobre esta base a 0,746 peniques por kW-hora sin asignación alguna para el plutonio producido. Si aceptamos cifras conservadoras en cuanto a la conversión y el valor del plutonio esta cifra se reduce a 0,582 peniques por kW-hora. Sin embargo, el sistema de tal proceso de ciclo único es costoso y mediante un reciclado apropiado el costo puede reducirse a 0,5 peniques por kW-hora.

"Nuclear Engineering" Scholarship

Nuclear Engineering invites applications for a Post-graduate Scholarship to be awarded for the year 1956-57.

The objects of the Scholarship are to enable the holder:

(a) To pursue studies at post-graduate level directed towards some aspect of nuclear engineering, and

(b) To pursue an approved programme of research in some aspect of nuclear engineering.

The amount of the award will depend upon the circumstances of the successful candidate's case, but will usually be £350 per annum and will in no case exceed £400 per annum. The amount and duration will be assessed by the Selection Committee.

The normal duration of the Scholarship will be one year, or such longer or shorter period as may be approved.

Scholarships will be tenable at universities, technical colleges and other educational establishments (in the United Kingdom) approved by the Selection Committee.

GENERAL CONDITIONS

1. The candidate must be a British subject normally resident in the United Kingdom, with a university degree or its equivalent in engineering, physics, chemistry or metallurgy.
2. A candidate is required to submit a programme of work which he would undertake during the tenure of the Scholarship, together with an estimate of the cost of carrying it out, including personal expenses. Any other awards, allowances, etc., to the candidate, which would be concurrent with the *Nuclear Engineering* Scholarship, should be described.
3. The candidate is to furnish names and addresses of two referees who will be asked to advise the Selection Committee on the qualities of the candidate.
4. The award will be made at the absolute discretion of a Selection Committee.
5. The successful candidate shall devote his whole time to the programme of work proposed by him with such alterations as the Selection Committee may, with the candidate's agreement, approve at the time of the award.
6. At the completion of a Scholarship, a report is to be submitted, but the company may require interim reports on the work from time to time.
7. Prospective candidates may obtain forms of application from: The Editor, *Nuclear Engineering*, Temple Press Limited, Bowling Green Lane, London, E.C.1.
   All applications should reach the Editor by July 31, 1956.
8. Applications received will be considered by the Selection Committee, and a short list (if necessary) prepared of candidates required for interview by the Committee in London. Approved travelling and subsistence expenses will be defrayed by the Company.
9. The Selection Committee reserves the right to elect such candidates as it may approve and the grounds on which particular candidates have been elected or rejected need not be given.
10. In the case of an award for one year payments will be made as follows: October1—one-half of award, January 1—one-quarter, April 1—one-quarter.
11. The Selection Committee may terminate a Scholarship at any time if it is not satisfied with the progress or conduct of the student.
12. Candidates should furnish evidence when required to the Committee that their programmes of work have the approval of the head of the institution or department in which they propose to work.

The Designer and Radiation Protection

When designing equipment and processes for the handling of radioactive materials consideration must be given to safety from direct radiation and contamination, concomitant with flexibility of operation and feasibility of maintenance. The designer must work in collaboration with specialists and understand the various problems that are involved.

by
H. J. DUNSTER, A.R.C.S., B.Sc.
Health Physics Division, A.E.R.E., Harwell

THE last decade has seen a vast increase in the supply of radioactive materials. At the same time our methods of detection have become more sensitive so that whilst the nuclear power engineer now thinks in terms of megacuries, the research worker and the biologist may be worrying about small fractions of a microcurie. It is this enormous range of quantities, as much as the special problems of radioactivity, that throws such a load on the designer of facilities for handling radioactive materials.

The Basis of Design

Design, in the sense in which it is used here, is not confined to the design of buildings and plant. It includes the design of experiments, of equipment, of technical processes and of whole installations. In all these applications the aim of the designer is similar. He is, or should be, attempting to supply the required facility so that it functions in the required way and can be operated conveniently, economically and safely. Clearly the designer must reach a compromise: the three aspects of operation are frequently incompatible and the basic requirements of the facility may militate against all three. The designer's problems are further complicated by the need to consider not only normal operation, but also changes in operating procedure and abnormal operation, although this last feature should be rare. The design must therefore be flexible and reliable and at the same time able to deal with abnormalities ranging from minor aberrations to complete breakdown. Maintenance work, either routine or following a breakdown, is not always regarded as a concern of the designer, but it is a subject which he should not overlook. Careful attention to detail during design will often greatly simplify the problems of maintenance.

None of these design problems is peculiar to the handling of radioactive materials, but, as McLean[1] has pointed out in the first paper of this series, special problems are introduced by the high toxicity of radioactive materials, by the fact that the radiations emitted can be damaging even when the material itself is safely confined, and by the grave nature of the injuries which radiation can cause. These special problems fall conveniently into three groups—the control of external radiation; the control of contamination of air and surfaces; the production and disposal of waste.

The designer is rarely able to draw clear-cut divisions between these groups—usually his solution of the problems in one group will affect the problems in others—and he must therefore keep all the problems before him throughout his design work. He must also co-operate closely with the operator of the facility he is designing, not only to ensure that he meets all the operating requirements, but also to see that the operator appreciates the rationale of his design. This integration of design and operation is a vital part of the designer's work and it does not end with the commissioning of the plant or facility. It is also essential that the operating experience should be fed back to the designer in a scientific manner. This feed-back may take many forms—from casual conversation to detailed operational research—but it should always be recognized as an important source of the designer's information.

At all stages of his work, the designer has to have ready access to specialist advice. One of the specialists involved should, in almost all cases, be an occupational hygienist because occupational hygiene bears on the problems, not only of safety and health, but also of convenience and economy of operation. When radioactive materials are to be handled, the hygienist will be a specialist in radiation protection—a health physicist as he is often, somewhat misleadingly, called. The health physics team will also be involved in the subsequent operation of the facility under design, and the importance of passing back and of properly interpreting its operating experience cannot be over-emphasized.

In short, the designer of any facility appears as one of a collaborating team relating the special problems of handling radioactive materials to the more conventional problems of meeting the operator's requirements. This relationship is shown diagrammatically in Figure 1.

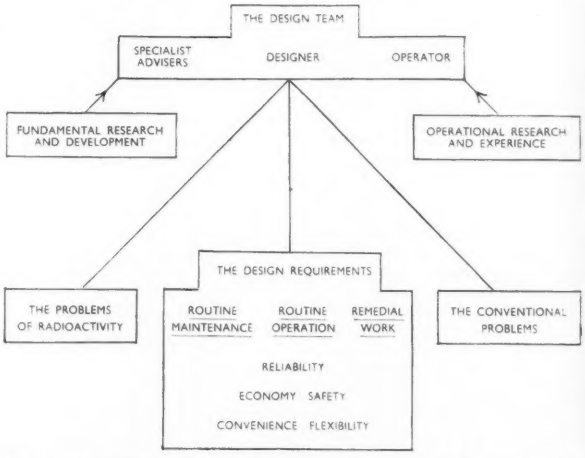

Fig. 1. Interrelationship of the design team and the design requirements.

The Control of External Radiation

The control of the dangers of the radiations from radioactive materials which are themselves safely confined is fairly straightforward, although some of the problems posed are numerically somewhat involved. The designer's aim is to allow the operating and maintenance teams to do their job with the minimum of restriction, but at the same time without receiving unacceptably high radiation doses.

In considerations of acceptable levels of radiation, it is usually convenient to consider two types of area in the vicinity of radiation sources. The first type of area is that which will regularly be occupied by operating staff. Clearly, the radiation levels in such areas must normally be maintained below the recommended maximum permissible levels. The second type of area is that which will not normally be occupied, but to which occasional access is required. In these areas the designer has a choice of policy. He can adopt a conservative attitude, and one which gives the operator the greatest possible freedom, by treating them in exactly the

same way as the regularly occupied areas. Alternatively, by arrangement with the operator, he can allow radiation levels to rise above the m.p.l. and rely on the operator to keep weekly doses down to acceptable levels by the control of access and of time spent in the area. It has been the practice until recently to regard certain regions, particularly in reactors and chemical plants, as permanently inaccessible but experience with the Chalk River reactor, N.R.X., and with the reactors and chemical plant at Windscale has shown that this view is unwise. A combination of local shielding, the removal of some of the radiation sources, and carefully rehearsed procedures, has permitted occasional emergency entry to areas not intended to be accessible. Such access could often be greatly simplified by suitable attention to the design of these areas:

Having decided on suitable levels of radiation, the designer can assess the factors which affect these radiation levels. If he has any choice in the matter, he should first consider the source of radiation and in particular he should attempt to keep the activity to as low a value as practicable. It may also be possible in some cases to select a source whose radiation is easily stopped in shielding materials. For example, caesium-137 and thallium-204 have similar beta energies and either could be used for preventing the build-up of static electricity. However, the caesium isotope emits much more gamma radiation than thallium and it is thus very much less suitable, because a heavy and cumbersome shield would have to be fitted to absorb this gamma radiation. When he has made his choice of source, the designer can give his attention to the remaining two factors which affect radiation dose-rates—distance and shielding.

In simple cases, where the dimensions of the radiation source are small, the radiation intensity decreases as the square of the distance from the source. In many practical cases the contribution of scattered radiation from surrounding materials is large enough to modify this relationship, and at short distances the dimensions of the source will also have an effect. For gamma rays and neutrons, both these effects usually result in a smaller change of intensity with distance than would be given by the inverse square law. For beta radiation, the attenuation by air causes a more rapid decrease at distances of the order of a foot or more. In spite of these limitations it is convenient to use the inverse square law to give a preliminary assessment of the value of distance as a method of reducing radiation intensities, but in critical cases more careful calculations will be needed. In only a few circumstances will distance be adequate to reduce the levels of radiation to the required values and it will often be necessary to use shielding materials.

Shielding

The problems of the theoretical design of shielding are complicated because several types of radiation have to be considered and because the processes of interaction of radiation and matter are complex. In particular, these interactions usually cause scattering of the radiation as well as energy absorption. It is the analysis of the behaviour of this scattered radiation that causes the theoretical complexities.

The practical problems of beta shielding are relatively simple because beta particles can be completely stopped in thin shields, and it is therefore not normally necessary to estimate the thickness required to give a selected attenuation. Data on the maximum ranges of beta particles are given by Katz and Penfold[2] and these figures, expressed in terms of surface density (milligrammes per square centimetre), can be applied without serious error to any absorbing material of atomic number up to about 30. When large beta sources are to be handled a slight complication is introduced. The stopping of beta particles in matter, particularly in heavy materials, results in the transformation of part of the beta energy to electromagnetic radiation—Bremsstrahlung. This radiation is more penetrating than the primary beta radiation

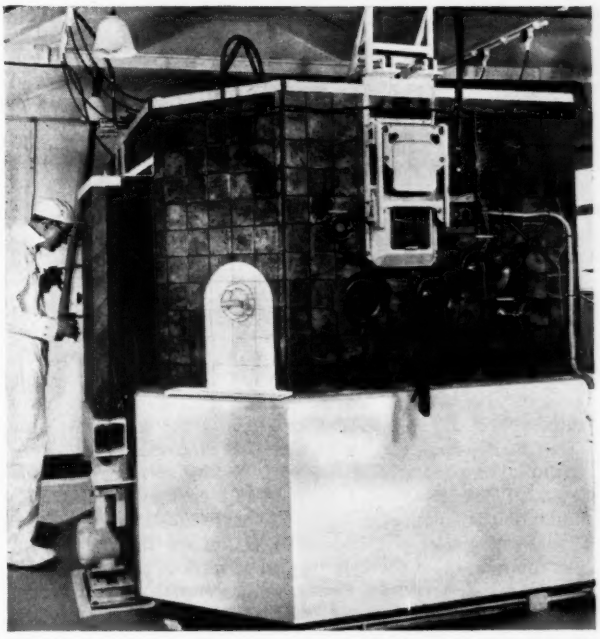

Fig. 2. An example of the use of lead shielding in the handling of irradiated specimens.

and may therefore need serious consideration when beta sources of the order of a curie or more have to be handled.

Shielding against gamma radiation is a great deal more difficult, because gamma radiation cannot be completely stopped in matter. Thus no thickness of shield gives complete protection. The degree of protection depends greatly on the behaviour of the scattered radiation and thus on the geometrical arrangement of the source, the shield, and the detector. Some examples of suitable thicknesses of common materials can be derived from data given by Fano[3] which assume as large a scattered contribution to the emergent dose rate as is likely to be met in practice.

The designer can often make considerable economies in shielding by making the greatest possible use of the principle that only regularly occupied regions need to be fully protected. As a typical example, it is usually possible to design high-activity shielded cells with a roof giving a factor of perhaps 100 less shielding than the shielding on the operating face. Such relaxations are not without their dangers: scattered radiation may increase exposure levels at the working positions, and maintenance work on future modifications may be greatly complicated.

The choice of shielding materials is governed by a variety of factors. If the gamma energies are predominantly in the region of 1 to 3 MeV the attentuation of the shield is fixed primarily by the mass per unit area. A secondary effect, more marked at higher and lower gamma energies, is the increased effectiveness, even on a mass basis, of materials of high atomic number. Thus a lead shield can be thinner than a concrete shield by a factor rather greater than the ratio of the densities. High density materials are more expensive than concrete but have overwhelming advantages in at least two cases. When a source of small dimensions has to be shielded by a thick shield on all sides, the shield thickness will be roughly inversely proportional to the density, while the mass will be nearly proportional to the cube of the thickness. A thin, dense shield will clearly be very much lighter than a thicker one of lower density, and lead or steel is therefore commonly used for transport containers.

The second example is for a shield through which a number of manipulators have to pass. The cost of lead for such shields is high, but the manipulators can be fairly

simple. A thicker, low density, shield would require very much more complicated manipulators. In contrast, for chemical engineering plant where controls can be remotely operated fairly easily, the cheaper concrete shield is usually preferable.

Figure 2 shows an example of lead used to shield a closed box in which irradiated specimens are removed from the sealed cans in which they were irradiated. The top of the box is not shielded and mirrors are used to supplement the views through the lead glass windows. The scattering of gamma radiation from the air and the roof limits the gamma activity which can safely be handled in this box to about 50 curies.

The Control of Contamination

Because of the high toxicity of most radioactive materials, great care has to be taken to ensure that they do not contaminate the workers' environment. This contamination is much more difficult to control than is external radiation because any manipulation of unsealed materials causes some spread of the material on to surrounding surfaces and into the air. The basis of the successful control of this contamination is defence in depth, and there are three main lines of defence. The first is the selection of the process or operation so as to create as little spread of material as possible. The second is containment, usually double containment, of the process or operation to prevent contamination of the working area. The third is the design of the working area and of its access arrangements so that any contamination which does occur is prevented from spreading to other areas. In principle, the designer's aim is clear: he should halt contamination at the first or second line of defence. In practice, the problems of operation, particularly of abnormal or maintenance operations, sometimes force him to depend considerably on the final barrier. The fundamental objection to depending on this last stronghold is the fact that the radioactive contamination has then become part of the workers' normal environment. In order to work safely in this environment they may have to work in unnatural conditions, perhaps even including breathing apparatus. The designer's first interests must therefore be the choice of process and its containment.

The choice of process or operation is not often solely in the designer's hands, but he should strive to avoid the production of dusts, mists, splashes and fumes, and to minimize the transfer of materials from one vessel to another. Such processes as sampling and dismantling for maintenance work require special attention, because they are very prone to cause contamination. The importance of eliminating the risk of fire, explosion, and other accidents is greatly enhanced when radioactive materials may be involved, because the effects of the release of radioactivity not only complicate the local emergency procedures, but may have repercussions outside the range of the initial incident. While considering the choice of processes, the designer should also consider the possibility of selecting the radioactive material. Apart from the obvious step of using as little radioactivity as possible, there are often advantages in using material of low specific activity; for example, dilute solutions rather than concentrated ones. A further aspect to be considered is the toxicity of the material. When a choice is available, the problems may be simplified by many orders of magnitude because the toxicities of radioactive materials, assessed for chronic exposure cover a range of which the extremes differ by a factor of about a million.[4]

Containment

The subject of containment is a complex one, not only because containment can range from simple catch trays under glass apparatus to complete buildings, but also because it may often have to be combined with shielding. In practice, methods of containment can be divided into three classes, although the dividing lines are not always completely clear.

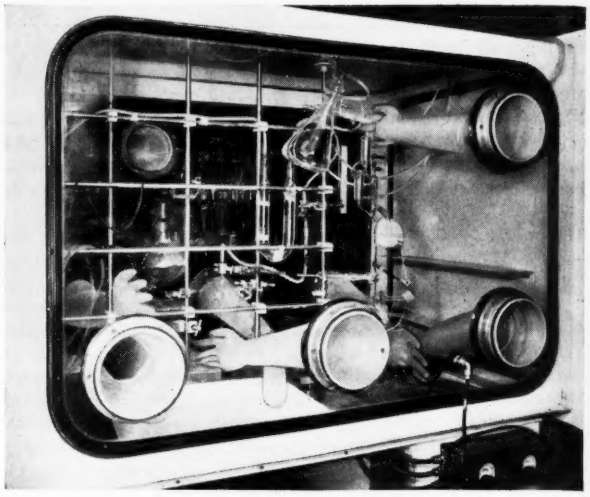

Fig. 3. For complete and true containment it is necessary to surround the process in some form of sealed container, such as a glove box.

The first class consists of the double containers, driptrays, duct linings, tank sumps, and the multiplicity of devices to minimize the effects of leaks and spills of radioactive materials. The second class is typified by the laboratory fume cupboard, and depends on a copious flow of air to isolate the radioactive material from the operator. The principal problems posed by this type of installation are those of ventilation. An air flow rate of at least 100 linear feet per minute, sometimes of 400 feet per minute, is needed and this air is likely to become contaminated and thus to present a problem in waste disposal. At the same time a suitable volume of clean, heated air must be supplied to the working area. The third class is the only one which gives complete and true containment. It makes use of sealed containers completely surrounding the process. In practice, such containers, for example, glove boxes, such as the one illustrated in Figure 3, require some ventilation as this reduces the importance of minor leaks, but the volume flow can be very small and the problems of filtration and building ventilation are greatly simplified. Care has to be taken in the design of the ventilation of the enclosure because clogging of the filters or the sudden evolution of large volumes of gas may cause positive internal pressures which the container cannot withstand. In some cases, the container is specially designed to withstand any positive pressure which can reasonably be expected. Containment of this type is being built round the fast fission reactor at Dounreay so that, in the unlikely event of an accident to the reactor, the results of the accident would be confined to the reactor building. Because of the possibility of a considerable evolution of heat, and consequently of a large pressure rise, the container has been designed in the form of a steel sphere, 135 feet in diameter.

Perhaps the most widespread problem associated with containment is that of access. Access is usually necessary for introducing and removing radioactive and other materials, for controlling the process for sampling and for maintenance work. Much of this access can be achieved without destroying the integrity of the containment, but some of it will involve removing part of the containing barrier, or require physical entry into the area of containment. The designer can be of great help to the operator if he foresees this need and arranges suitable facilities. These may be as simple as the provision of an open space in which the operator can establish temporary contamination control equipment, or as complex as a complete maintenance area with provision for using special protective clothing such as pressurized suits.

Another problem of access is that of the movement between

the operating area and ancillary facilities such as stores, offices, canteens, rest rooms, and lavatories. Two entirely different approaches are possible to this problem. A number of operating areas can be grouped together with common access through a change-room and with little or no restriction on movement between them. Some of the offices, rest rooms, lavatories, workships, and stores can be included within the active area. Canteens, the main offices, workshops, and stores, and the other facilities required are usually kept outside. The alternative method, which is more difficult to control, but which is very much more flexible, involves treating each operating area on its own. These areas can then be distributed as necessary among the general site facilities, and local change rooms can be provided as convenient. Movement between active and inactive areas is then fairly simple, but movement between separated active areas is more complicated than between grouped ones. Figure 4 shows part of a change room serving a single wing of a building: a change room for a group of buildings would differ from this only in detail and in size. As a general rule, large-scale work with high levels of activity is better done in large, self-contained active areas, while experimental work at lower levels can often be done in small active enclosures within inactive areas.

In all work with unsealed radioactive materials, decontamination plays an important part. This is particularly true of maintenance work and remedial work after accidents, but it may also be an essential aspect of normal operations. The designer can be of great help by bearing this in mind when selecting the materials and layout for both his process and its surrounding operating areas. His aim should be to employ smooth, chemically inert, non-ionic, non-absorbent, surfaces, free from cracks and awkward corners. Unfortunately, many of the standard materials of construction are highly unsatisfactory, and the more suitable materials are expensive. The conditions inside closed cells and cabinets may also be very severe with attendant corrosion problems. As always, the designer must reach a compromise, which usually takes the form of conventional basic materials—concrete and mild steel for example—with a high quality surface finish, such as a high gloss or chlorinated rubber paint. Stainless steel has a place in permanent chemical plant, but rarely justifies its cost in other applications.

Figure 5 shows some of the principles of contamination control applied to a laboratory intended for use with curie quantities of beta-gamma emitters. Much of the work will normally be conducted in the fume cupboards in which lead bricks can be built up to form a gamma shield. Some operations, involving only small amounts of radioactivity, can more conveniently be done on the open benches and these are therefore fitted with tops which are easily decontaminated and, as a further precaution, a disposable bench cover is also used. The illustration also shows a portable contamination monitor, indispensable in a laboratory of this kind, and a built-in radiation monitor. This unit, with its ionization chamber above the fume cupboards, is of very limited value

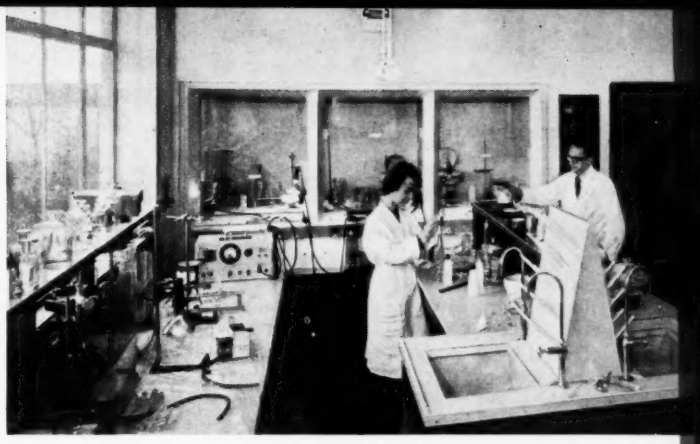

Fig. 5. Some of the principles of contamination control are applied to this laboratory intended for use with curie quantities of beta-gamma emitters.

in a general purpose laboratory and is better confined to areas such as the working faces of research reactors, where faulty operation may cause high radiation levels without itself being obvious. A more useful installed equipment in laboratories is an air sampler capable of drawing a representative sample of the laboratory air through a filter paper which can subsequently be counted for the appropriate radioactivity. Refinements, such as the use of a moving filter paper and built-in counting units to give a continuous record, are helpful in giving an early warning of air contamination, but their complexity is justified only in exceptional circumstances. It is a great deal more important for the designer to concentrate on the process, its containment, and its immediate surroundings than to provide complex installed health instruments.

The Production of Waste Materials

Most operations involving radioactive materials give rise to liquid, gaseous, and solid radioactive waste products. Apart from the interest of the designer in the provision of suitable disposal facilities, he should also bear the problems in mind during his design of the primary facilities. He should first aim at keeping the amounts of radioactivity in such waste to a minimum. Secondly, he should treat the production and disposal of the waste as an integral process so that the waste is produced in a form suitable for disposal.

There are two fundamental ways of disposing of radioactive waste: on the one hand, the waste can be dispersed and diluted to safe levels in the natural environment, whilst on the other hand, the radioactive components can be concentrated into a convenient form and stored. The designer's approach to the production of waste depends on which of these methods he expects to apply. If the waste, either liquid or gaseous, is of large volume and contains only small amounts of activity, it is usually uneconomic, and also unnecessary, to remove the radioactive material. The designer must therefore ensure that such wastes are free from the risk of occasional high level contamination, and that the waste is otherwise suitable for release to man's environment. If the waste is to be stored or purified the form in which it is produced will require very close attention. Liquid wastes should be suitable for chemical or physical concentration to small volume, or for chemical treatment to remove the activity as a secondary low volume waste. Solid wastes should be capable of volume reduction by incineration or baling. Gaseous wastes should be free from inactive dust which would clog filters or add to the solid content of the secondary wastes produced by air cleaning equipment such as cyclones and electrostatic precipitators. All the material for eventual storage must be in a stable chemical and physical form,

Fig. 4. Part of a change room serving a single wing of a building.

because the period of storage may have to be exceedingly long.

The Avoidance of Criticality

The present power programme[5] depends entirely on the process of fission as its source of energy. For this reason increasing quantities of fissile material are being handled by the United Kingdom Atomic Energy Authority and, more recently, by industry. Whenever the amounts of pure fissile isotopes exceed a few hundred grammes, attention has to be paid to the possibility of producing a self-sustaining chain reaction—the condition known as criticality. The effects of such a reaction would depend greatly on the way in which the condition had been achieved, but would in no case amount to a major explosion. Local overheating and possibly local disruption of plant and equipment is the worst that might be expected. On the other hand, the local radiation levels would be exceedingly dangerous, and might be lethal at distances of the order of tens of yards. The co-operation between the designer and the operator must clearly be of a high order to ensure that the possibility of an accident of this kind is made vanishingly small.

The designer has several different methods of criticality control at his disposal. He can limit the quantity of fissile material in the system, remembering the possibility of hold-up in a continuous process and of batch doubling. He can fix the concentration and design his vessels so that they are safe even when full, and in this case he must bear in mind processes which can change the concentration—dilution if he is using highly concentrated material, concentration, for example by precipitation, if he is using dilute material. Finally, he can sometimes make use of "ever-safe" vessels which, because of their shape and size, will be sub-critical at all the possible concentrations of fissile material. Whichever method of control is chosen by the designer, he must also make allowances for the possible addition of reflectors or the removal of neutron-absorbing material.

The Summing Up

The designer's task is rarely a simple one and undoubtedly it is greatly complicated by the special problems of radioactivity. Nevertheless, these problems, disconcerting as they may be because of their unfamiliarity, are capable of logical solution, and the principal factors at the disposal of the designer are summarized in the following table.

External radiation	*Contamination*
Limitation of access	Choice of process
Size of source	Toxicity of material
Type of radiation	Containment
Distance	Change rooms and layout
Shielding	Structural materials
Waste products	*Criticality*
Form of arising	Quantity
Treatment for dispersal	Concentration
Treatment for storage	Shape
	Moderators and reflectors
	Neutron absorbers

Although experience is still limited and the fundamental biological data are still incomplete, the information available to the designer is steadily increasing and whilst some changes in emphasis must still be expected, there is now little excuse for the designer who fails to recognize the principal pitfalls or, having recognized them, is excessively cautious.

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L'Ingénieur-Dessinateur et la Protection contre la Radiation

Cet article a été écrit dans le but d'énoncer les questions dont le dessinateur doit tenir compte lors de l'étude des moyens appropriés ayant trait aux expériences et installations entraînant des dangers de radiation. Il doit faire la part des trois types de danger discutés dans le mémoire du Dr. McLean au premier article de cette série et essayer de trouver un système de compromis. Pour le contrôle de la radiation externe il doit considérer s'il faut prévoir toutes les zones avec un niveau de taux au-dessous du m.p.l. (limite minima possible) ou permettre à certaines zones de s'élever au-dessus de ce chiffre, avec le contrôle approprié exercé à l'accès.

Dans les applications des radio-isotopes, le choix de la source a une importance capitale et le rapport de r2 est normalement suffisant pour l'évaluation des dangers à distance. La protection contre les rayons béta ne présente pas normalement de grands problèmes, mais pour les sources multicurie des précautions devront être prises pour l'évaluation des effets de Bremsstrahlung. Le choix entre les matériaux de densités basse et élevée dépend de considérations d'espace et de poids lors de la protection contre les rayons gamma.

La contamination est contrôlée en assurant une double inclusion et des zones de travail isolées des zones inactives, mais on devra tenir compte du processus impliqué pour éviter de travailler sur des poudres, pulvérisations, etc.

Der Konstruktör und der Schutz gegen Strahlung

Der Artikel wurde geschrieben, um die Probleme zu ventilieren, die der Konstruktör berücksichtigen muss, wenn er Einrichtungen für Forschung und Werke entwirft, bei denen mit Strahlungsgefahr gerechnet werden muss. Er hat drei Arten von Gefahren zu bekämpfen, die in Dr. McLean's Arbeit, der ersten in dieser Reihe, diskutiert werden, und er muss versuchen, zu einem Kompromiss zu gelangen, wenn er alles berücksichtigt. Für die Kontrolle äusserer Strahlung muss er überlegen, ob er das ganze Gelände für eine Strahlungshöhe, die unterhalb der erlaubten mittleren Strahlung (m.p.l.) bleibt, entwerfen soll, oder ob in einigen Teilen eine höhere Strahlung zugelassen werden kann, wobei eine geeignete Kontrolle beim Zugang zu diesen Stellen vorzusehen ist.

Bei Anwendung von Radioisotopen ist die Wahl der Quelle von äusserster Bedeutung. Der Faktor r^2 ist normalerweise ausreichend, um die Grösse einer Gefahr inbezug auf Distanz auszuwerten. Abschirmung gegen Beta-Strahlen macht gewöhnlich nur geringe Schwierigkeiten, jedoch muss man sorgfältig vorgehen, wenn man Wirkungen der Bremsstrahlung bei Millicurie-Quellen auswertet. Die Wahl zwischen Materialien hoher und niedriger Dichte hängt von Fragen des Raumes und des Gewichtes ab, wenn es sich um Abschirmung gegen Gamma-Strahlen handelt.

Die Verseuchung wird damit kontrolliert, dass man die Abschlusswände doppelt vorsieht und die Arbeitsbezirke von den Bezirken ohne jede Aktivität isoliert, jedoch muss man den jeweiligen Arbeitsprozess berücksichtigen und die Arbeit mit Pulvern, Spritzflüssigkeiten usw, vermeiden.

El Proyectista y la Proteccion contra la Radiacion

Este artículo ha sido escrito con vistas a plantear los problemas con que habrá de enfrentarse el proyectista al estudiar los medios de que habrán de valerse en experimentos y en empresas que presenten riesgos de radiación. Deberá estudiar los tres tipos de riesgo discutidos en el informe del Dr. McLean en el primer trabajo de esta serie y procurar encontrar un sistema de conciliación. Al intentar controlar la radiación externa deberá tener en cuenta si habrá de plantear todas las zonas a un nivel proporcional por bajo del m.p.l. (límite mínimo posible) o permitir que en ciertas zonas rebase esta cifra ejerciendo un control adecuado sobre el acceso.

En las aplicaciones de radio-isótopos la selección de origen de primordial importancia y la relación r^2 es normalmente adecuada para avaluar el riesgo a cierta distancia. La protección contra los rayos beta generalmente presenta escasos problemas, pero debe ejercerse gran cuidado con los orígenes policurios al avaluar los efectos Bremsstrahlung. La elección entre material de alta y baja densidad depende de consideraciones de espacio y peso al hacer la protección contra los rayos gamma.

La contaminación se controla con la doble represión y el aislamiento de las zonas de trabajo de las zonas inactivas, pero deberá tenerse en cuenta el procedimiento adoptado para evitar trabajar sobre polvos, rociadas, etc.

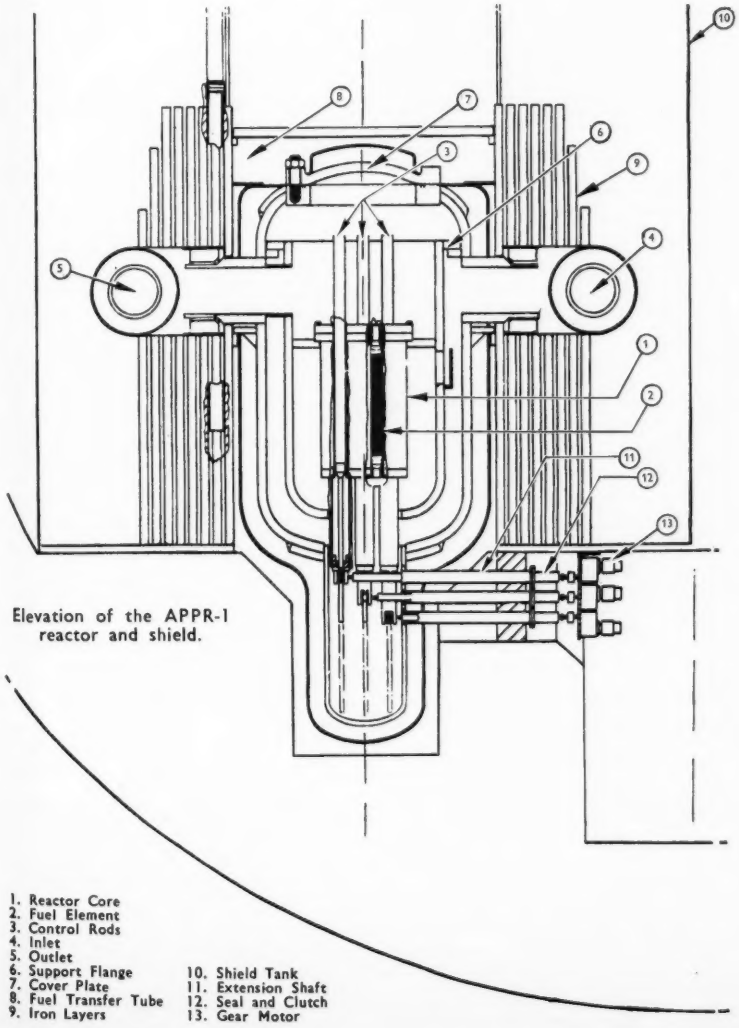
The Army Package Power Reactor

The Alco pressurized-water-reactor transportable power unit, designed expressly for military purposes, is expected to diverge in the spring of next year. It will generate a total of 2,105 kW of electricity through a conventional steam turbine system.

WITH a view to producing a transportable power unit, notably for military purposes, a contract was awarded to the American Locomotive Company in December, 1954, for the design and construction of a prototype plant. Work began on the construction in October, 1955, and the reactor is expected to diverge in the spring of 1957. The reactor system now under construction is a pressurized water moderated reactor followed by a heat exchanger generating steam which is fed through a conventional steam turbine. Information released by the company shows that the plant has been designed to generate a total of 2,105 kW of which 180 kW will be fed back into the system to give an output of 1,925 available kilowatts.

The reactor core is made up of 40 plate-type fuel elements of stainless steel and enriched uranium. These are $2\frac{3}{4}$ in. square and 22 in. in active length and are arranged in a regular pattern to form a 20-in. square with the corner sections absent. The fuel elements are fitted with inlet and outlet end boxes giving an over-all length of nearly 3 ft. The core is contained within the reactor vessel—4 ft. in diameter and 8 ft. high, and cooling water is fed into the bottom of the reactor vessel and directed to the entrance plenum chamber, through the fuel elements, the exit channel, thence to the heat exchanger. In addition to the fuel elements are five control rods, four of which are coupled together to act as shut off, and one is a fine control. The control rods are of a similar shape to the fuel elements and consist of square hollow basket-type structures into which removable fuel and absorber elements are inserted. The drive to the control rods is taken through the bottom of the reactor vessel and out to the control drives at the side of the vessel through rack and pinion mechanisms.

In the prototype installation the shielding has been augmented to assist easy operation. The primary shielding consists of layers of 2 in. thick iron in a water tank of 47 in. radial thickness. Outside this has been erected a 2 ft. concrete-lined, steel container, but this would be unnecessary in a remote location.



Elevation of the APPR-1 reactor and shield.

Primary coolant

The primary coolant is designed to circulate 4,000 gallons per minute of water through the reactor and heat exchanger. Water from the reactor emerges at a temperature of 450°F and is cooled to 431°F at full load. Circulation is maintained by two canned-rotor type motor-driven pumps, one of which is a stand-by but is provided with a small backflow to boost the temperature in the static pipe. Pressure is maintained in the primary loop at 1,200 p.s.i. by means of two 50 kW heaters operable in increments of 10 kW. These units are individually thermostated to provide "velocity control" on the temperature. The maximum fuel temperature is expected to be 567°F.

Secondary system

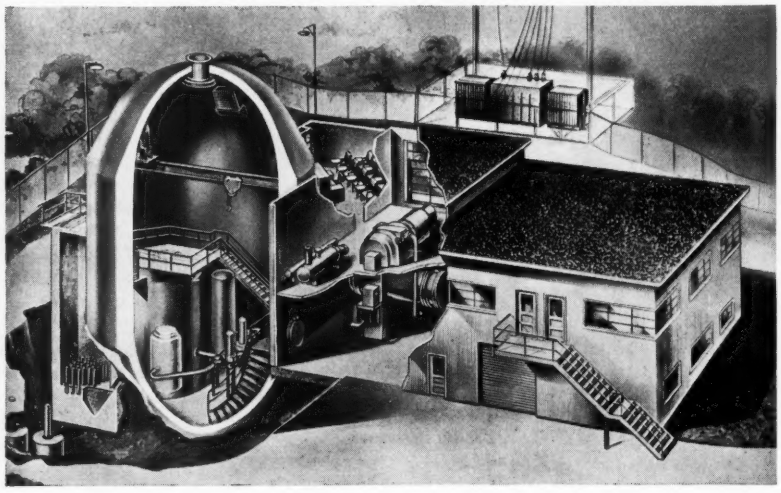
At full load, steam is formed in the heat exchanger at 200 p.s.i. and 382°F. With decreasing load this temperature will increase until at no load, pressure will be 423 p.s.i. The turbine is designed for 250 p.s.i. inlet pressure and is provided with a steam throttle to prevent this figure being exceeded.

The generating plant consists of a 2,500-kW, 4,160-volt, 3-phase 60-cycle unit. Provision is made at a sub-

station for transforming this voltage down to normal line values.

Safety considerations

The control rods and safety rods are not servo fed, reliance being placed on the large negative temperature coefficient of the reactor. To guard against the dangers of a run-away the vapour container has been designed to accommodate a sudden increase of pressure and to contain even a large excursion followed by the release of a substantial fraction of the 100 million curie of fission product activity in equilibrium at full power. The vapour container consists of a steel cylinder 36 ft. in diameter and 64 ft. high of $\frac{7}{8}$ in. steel with hemispherical ends of $\frac{1}{2}$ in. thickness. This structure is designed to withstand a surge pressure of 65 p.s.i. To protect the vessel from rupture by high speed missiles conceivably resulting from an interior explosion, the container is lined with 2 ft. of concrete, which gives additional biological shielding.



Artist's impression of the Army Package Power reactor showing the vapour container (left). It is designed so that its components may be transported by air.

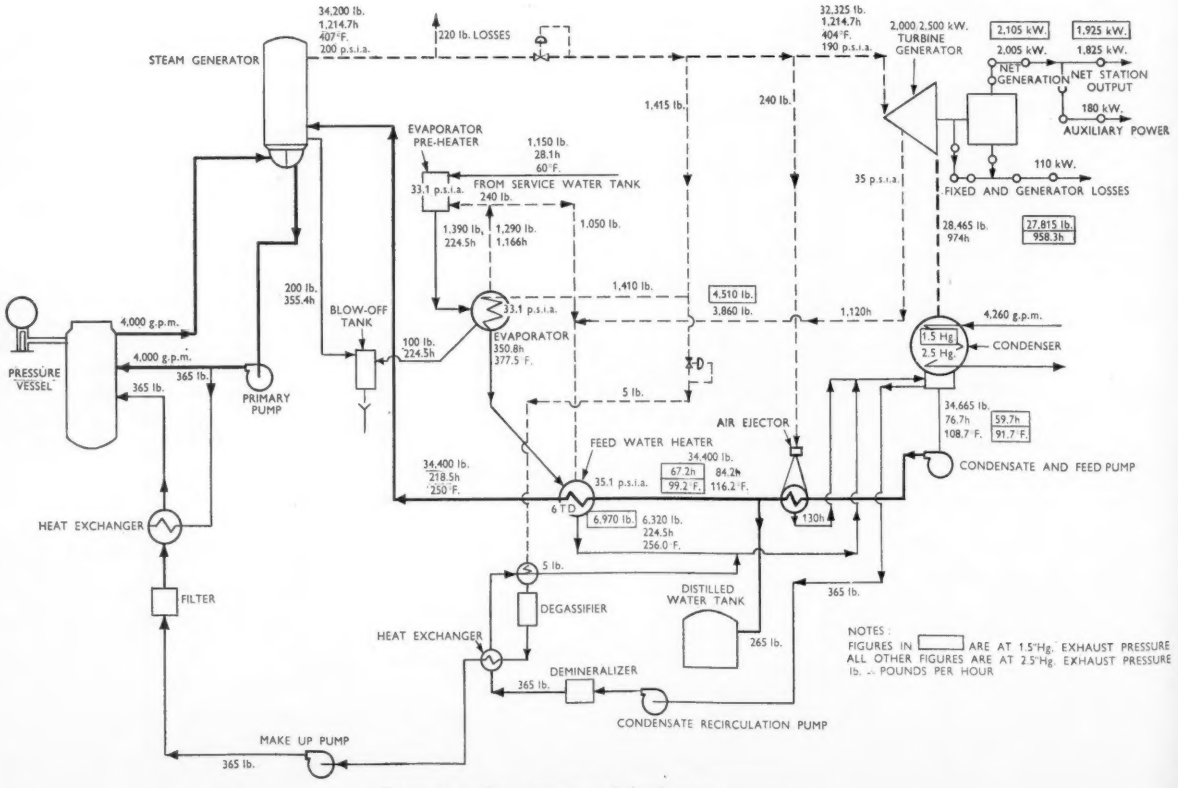
Costs

The capital and running costs of a reactor of this output are considerable but the company hope that in the 10 MW output region an over-all cost comparable with Diesel generation in remote localities is possible. Kenneth Kasschau of Alco has prepared a tentative costing based on the assumption that the design background of a 10 MW plant is complete. Certain of the figures must be treated with reservation and are liable to modification when operating experience has been gained.

Charge for fissile material is based on the lease charge figure quoted by Admiral Strauss at the Geneva conference of $25/gram of contained U 235, and manufacture of the fuel elements on the tenders submitted by industry for the APPR-1 design.

For a production type reactor, in which development can be neglected, direct fuel costs, excluding fabrication of the elements, has been estimated at 6 m./kWh. This fabrication has been quoted by a number of companies at approximately $75,000, thus adding a further $2\frac{1}{2}$ m./kWh and bringing the total fuel cost to $8\frac{1}{2}$ m./kWh.

Official figures are not available for costs of reprocessing—the techniques



Primary coolant, steam and feed-water systems.

being subject to security restrictions. The assumption is made that high burn-up figures will be possible which even with quite large reprocessing costs will only add 1 m./kWh to make the over-all fuel cost 9½ m./kWh.

Other operating costs are also difficult to estimate but taking a figure of 1½ m./kWh as derived from conventional plant experience a total operating cost of 11 m./kWh is arrived at.

Capital costs are again subject to considerable uncertainty but estimates indicate that the investment in a plant for which development was complete would be equivalent to 5.8 m./kWh at 80% load factor. The total plant cost would, therefore, be 16.8 m./kWh. Whilst this figure is considerably above that quoted for large scale power generation it is nevertheless of the same order as that experienced in really remote sites where no local fuel is available, such as Alaska.

Le Réacteur de Puissance en Paquet de l'Armée

Le développement d'une centrale à réacteur portative a été confié à l'American Locomotive Company à laquelle l'A.E.C. a donné un contrat le 10 Décembre 1954. On s'attend à ce que la première installation entre en fonctionnement au début de 1957. Le réacteur est du type à eau pressurisée dans lequel le noyau, composé d'uranium enrichi sous forme d'éléments d'acier inoxydable en combustible de type à 40 plaques, et de l'uranium enrichi donnant une dimension active totale de 20×20 pouces (508 mm.×508 mm.) par 22 pouces (559 mm.) de hauteur, est contenu dans une cuve de réacteur de 4 pieds (1,22 m) de diamètre et 8 pieds 5 pouces (2,56 m) de haut. De l'eau est faite circuler par le noyau à un taux de près de 18.160 litres par minute, entrant à une température de 431°F (222°C) et sortant à 450°F (232°C). La pression est maintenue dans ce circuit primaire à 1200 livres par pouce carré (84 kg/cm²) par un, pressuriseur à vapeur, la cuve contenant deux éléments de chauffe de 50kW. Le contrôle de la réactivité est effectué par 5 tiges semblables, dont 4 sont actionnées ensemble en cale et la cinquième pour le contrôle de précision.

La vapeur est produite dans l'échangeur de chaleur à 21 kg/cm² et à 382°F (225°C) à charge complète. La turbine a été conçue pour une pression maximum de 250 p.s.i. (17,58 kg/cm²) et à charge complète elle produira 2105 kW dont 180 kW sont renvoyés au système de réacteur. Dans une évaluation des aspects économiques d'une station génératrice de 10 MW de ce type, certaines suppositions laissent déduire le prix de revient de 16,8 m./kW/h. Cela suppose, toutefois, un facteur de charge élevé et un taux élevé de consommation.

Der Reaktor für den Tornister

Die Entwicklung einer für den Transport geeigneten Reaktor-Kraftlanlage ist der American Locomotive Company in Auftrag gegeben worden, mit der die A.E.C. am 10.Dezember 1954 einen Kontrakt abgeschlossen hat. Man erwartet, dass die erste Station Anfang 1957 in Betrieb sein wird. Der Reaktor gehört zur Klasse der Druckwasserreaktoren, bei denen der Kern, der aus 40 platten-förmigen Brennstoffelementen aus angereichertem Uranium in rostfreiem Stahl besteht, deren aktive Abmessungen insgesamt 20 Quadratzoll x 22" Höhe betragen, in einem Reaktorgefäss von 4' Durchmesser und 8' 5" Höhe untergebracht ist. Das Wasser zirkuliert durch den Kern mit 4.000 Gallonen/Minute; es hat beim Eintritt eine Temperatur von 431°F und verlässt den Kern mit 450°F. Der Druck wird in diesem Primärkreis durch einen Dampfdruckerzeuger auf 1200 p.s.i. (84,4 kg/cm²) gehalten, der von zwei 50 kW Heizelementen erzeugt wird. Die Kontrolle der Reaktivität wird mittels 5 gleichartiger Stangen ausgeübt, von denen 4 zusammen als Gruppe bewegt werden während die fünfte zur Feineinstellung dient.

Der Dampf, der in den Wärmeaustauschern erzeugt wird, hat bei Vollast 300 p.s.i. (21 kg/cm²) und 382°F. Die Turbine ist für einen Höchstdruck von 250 p.s.i. (17,58 kg/cm²) konstruiert und soll unter Vollast 2105 kW erzeugen, von denen 180 kW in den Reaktorkreis zurückgeleitet werden. Bei einer Schätzung der Wirtschaftlichkeit einer solchen 10 MW erzeugenden Anlage müssen gewisse Annahmen gemacht werden, wobei dann die Kosten auf 16,8 m/kW-Stunde errechnet werden können. Dies setzt allerdings einen hohen Belastungskoeffizienten und eine hohe Verbrennungsziffer voraus.

Reactor de Energía de Tipo Militar

La evolución de un equipo de energía por reactor de tipo transportable ha sido confiadad a la American Locomotive Company, a quien se otorgó el contrato por la A.E.C. el 10 diciembre de 1954. Se espera que el primer equipo esté en funciones en los primeros meses de 1957. El reactor es del tipo de agua a presión, en el cual el núcleo, compuesto de uranio enriquecido en forma de elementos de combustible del tipo de 40 placas de acero inoxidable y uranio enriquecido dando una dimensión activa total de 20 pulgadas en cuadro por 22 pulgadas de alto y contenido en un recipiente reactor de 4 pies (1,22 m.) de diámetro y 8 pies 5 pulgadas (2,56 m.) de altura. El agua circula a través del núcleo a razón de 4.000 galones por minuto (18.160 litros) entrando a una temperatura de 431°F y saliendo a 450°F. La presión se mantiene en este circuito primario a 1200 p.s.i. (84 kg/m.²) por medio de un recipiente de presión a vapor conteniendo dos calentadores de 50 kW. El control de la radioactividad se mantiene por medio de 5 varillas similares, 4 de las cuales operan juntamente como una cuña y la quinta para el control afinado.

El vapor se forma en los intercambiadores térmicos a 300 p.s.i. (21 kg/cm²) y 382°F (225°C) a plena carga. La turbina ha sido diseñada para una presión máxima de 250 p.s.i. (17,58 kg/cm²) y a plena carga generará 2105 kW de los cuales 180 kW son devueltos al sistema de reactor. En un cáculo económico de una planta de 10 MW de este tipo ciertas suposiciones permiten deducir un costo de 16,8 m/kW. Pero, esto supone un factor elevado de carga y una alta cifra de combustión.

Mono Pump Production

MONO PUMPS LTD., which in 1939 took over the textiles engineering firm Arnfields and was later absorbed into the Gallahers group, celebrated its 21st anniversary on June 14.

Original patents for the pump, which uses a direct coupled motor-driven rotor in a resilient stator, were taken out in the early thirties by a French engineer. Mono Pumps Ltd. was established in 1935 to develop and perfect this system. The pump has been found applicable to many types of fluid, ranging from water to fluidized flour which as a dry powder can be pumped at high speeds providing it is fluidized with an air pressure of about 5 lb./sq. in. The same pump is used also for the pumping of larger particles and has been used successfully for the pumping of water-borne peas. The rotor, which gives an appearance of a twisted bar, is machined from the solid by turning and grinding. The initial turning has been made automatic, the eccentrics in the head and tail stocks rotating one complete turn for a one pitch travel of the tool. The lathe is capable of high speed production with a tolerance in pitch and diameter of 0.002 in. The grinding of the final rotor is electronically controlled.

The company is at present experimenting with ceramic tools to increase production rates and preliminary tests have indicated that a considerable improvement in cutting speeds can be achieved. One of the problems associated with this type of tool is the rigid fixing of the tip to the holder in such a manner that subsequent thermal stressing does not cause fracture.

An interesting piece of control equipment that has been developed for the remote operation of machine tools is based on a hydraulic system which, it is claimed, follows as accurately and more quickly the actuating mechanism than the normal servo system.

Also under development is an oil circulation system, specifically designed for Diesel engine work in which provision is made for the electrostatic coagulation of contaminant, followed by filtration. The precipitator—known as the agglometron—contains an ionizing zone through which 300 microamp is passed from a high potential at a frequency of a thousand pulses per second.

It is expected that tests now taking place on a glandless type of pump will be complete in the near future and that Mono pumps will then be available in this form.

Statistics of Radiation Measurements

Before designing equipment or experiments based on radiation techniques it is necessary to know the limitations imposed by the statistical fluctuations of the detected radiation. The value of counting results is always determined by the statistical significance of the figures.

by
E. N. SHAW, B.Sc.

THE accuracy and speed at which operations can be performed using isotope techniques are more often than not determined by the statistical nature of the results. Before going into details on the limitations that these statistical fluctuations will impose in specific instances some recapitulation of the mechanism of decay must be discussed.

The instant of time at which a particular atom will disintegrate can be expressed as a probability only and no other exact information can be obtained. Furthermore, with a beta emitter or with a radio-isotope with a complex decay scheme no information is available before the disintegration of the energy of the radiation, only of the maximum energy that the β-ray can have, whilst the γ-radiation may have one of a number of defined energies. The mean behaviour of a large number of atoms of a particular isotope, however, is readily measurable and always the same. It is well known that no external influences such as magnetic fields, temperature, pressure, etc., exert any influence on the mode of decay or time of disintegration.

The net result of the probability function associated with the disintegration being equal and unalterable from one atom to the next is that the distribution of disintegration rates with time obeys an exponential function (the mean number of disintegrations in unit time being proportional to the total number of atoms available for disintegration) and the numbers of disintegrations occurring in equal time intervals when provision has been made for the decay obey a Poisson distribution law. The "spread" in this number is defined by the standard deviation σ which is the root mean square of the deviation from the mean figure. An alternative method of defining the error is in terms of the probable error. which is approximately 0.67σ.

It is interesting to note that the most probable time interval between two successive disintegrations is zero, irrespective of the mean rate of decay.

If a record is taken of the number of disintegrations recorded by a detector in a series of identical time intervals (where the half life is long compared with the experiment and where the apparatus used is "perfect") approximately one-third of the counts will differ from the mean by a value greater than $\pm\sigma$ and two-thirds will fall within these limits. The probable error is defined as the plus and minus limits outside which half the number will lie.

Fig. 1 is a curve of the odds against a particular error occurring, plotted against the difference from the mean, expressed in terms of the standard deviation. It will be seen that the chance of an event occurring, in which the count differs from the mean by more than twice the standard deviation, is one in twenty, whereas the chance of a count differing from the mean by more than four times the standard deviation is approximately one in 16,000.

The standard deviation of a number of equally probable random events N is $\sqrt{N}$; and a count totalling 10,000 will therefore be written as $10{,}000 \pm 100$ or $10{,}000 \pm 1\%$. Fig. 2 is a redrawing of Fig. 1, plotted for different values of total counts with the deviation expressed as a percentage of the mean.

If a number of different functions have to be related then the standard deviation of the final result can be deduced from the individual errors. In general terms this can be expressed as

$$\sigma_f^2 = \sum \left(\frac{\delta f}{\delta x}\right)^2 \sigma_x^2$$

The implication of this is that if two counts N_1 and N_2 of the same mean disintegration rate are taken in time intervals of t_1 and t_2 and the results are added then the standard deviation of the total $N_1 + N_2$ is given by

$$\sigma_n^2 = \sigma_{N_1}^2 + \sigma_{N_2}^2$$

which is the same result as counting over a total time of $t_1 + t_2$. With subtraction, however, the standard deviation is again $\sqrt{(N_1+N_2)}$ whilst the percentage error in the result increases to infinity if the counts are equal.

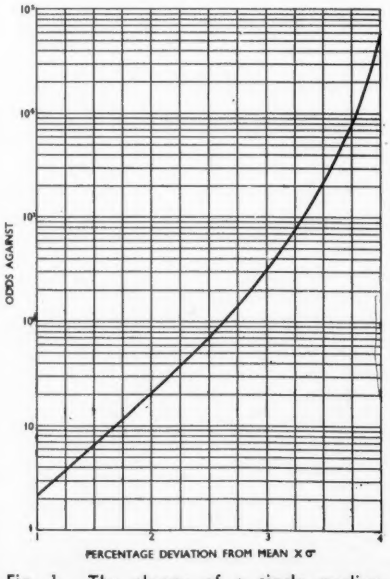


Fig. 1. The chance of a single reading lying outside the mean. Chance is expressed as odds against and the deviation from the mean as a factor of the standard deviation.

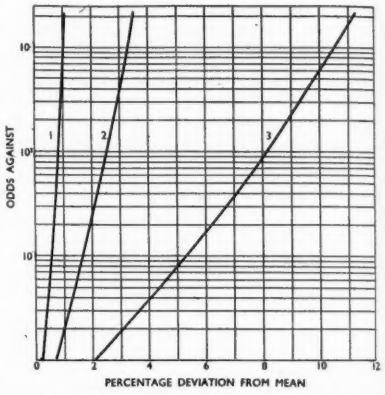


Fig. 2. Chance of a given count differing from the mean by an amount expressed as a percentage of the count. Curves 1, 2, and 3 refer to total counts of 100,000, 10,000 and 1,000 respectively.

A further example of the statistical fluctuations in a complex function can be obtained by examining the effect of taking the reciprocals of two counts, adding, and taking the reciprocal of the answer. This is a system that has been developed by Magee* to limit the effects of geometry on a uranium ore assessor. Two counters are used one on each side of the conveyor belt and pulses from each counter are fed through gating circuits which are triggered by the other counter. The recording circuit will thus accept pulses from each counter alternately. The maximum change in the count rate through a source movement from the central position (maximum rate) to the edge of the belt (minimum count rate) cannot be more than 35%. The approximate effect of the gating system is to add the counts in "series"—the analogy being made to condensers in electrical circuits.

* K. W. Magee, Austronic Engineering Laboratories, Melbourne, unpublished.

If the pulses in the set integrating time in the two counters are n_1 and n_2

Count recorded $N = \frac{n_1 n_2}{n_1 + n_2}$

$$\sigma_N^2 = \left\{\frac{\delta}{\delta n_1}\left(\frac{n_1 n_2}{n_1+n_2}\right)\right\}^2 \sigma_{n_1}^2 + \left\{\frac{\delta}{\delta n_2}\left(\frac{n_1 n_2}{n_1+n_2}\right)\right\}^2 \sigma_{n_2}^2$$

$$= \left(\frac{n_2^2}{(n_1+n_2)^2}\right)^2 n_1 + \left(\frac{n_1}{(n_1+n_2)^2}\right)^2 n_2$$

$$= \frac{n_1 n_2^4 + n_1^4 n_2}{(n_1+n_2)^4}$$

in the centre position where $n_1 = n_2 = n$

$$\sigma_N^2 = \frac{n}{8} \quad \text{and} \quad N = \frac{n}{2}$$

$$\text{giving} \quad \frac{\sigma_N}{N} = \frac{1}{\sqrt{2n}}$$

It is interesting to compare this figure with that obtained by direct addition of the counts when

$$N = 2n = \sigma_N^2$$

$$\text{so that} \quad \frac{\sigma_N}{N} = \frac{1}{\sqrt{2N}} \quad \text{(as above)}$$

If $n_1 >> n_2$

$$\text{then} \quad N = \sigma_N^2 = n_1$$

$$\text{and} \quad \frac{\sigma_N}{N} = \frac{1}{\sqrt{n_1}}$$

Returning to the reciprocal case when $n_1 >> n_2$

$$N = n_2$$

$$\text{and} \quad \sigma_N^2 = n_2$$

$$\text{giving} \quad \frac{\sigma_N}{N} = \frac{1}{\sqrt{n_2}}$$

It will be seen that the statistical fluctuations—as would be expected—are determined largely by the lower count. The variation in the over-all count and the associated standard deviation are plotted in Fig. 3 as a function of position, and compared with the results of a straight addition process.

The discussion above has been limited to a series of counts taken over set intervals where the beginning and end of the timing is defined. In many cases this is not representative of practical conditions as the counts will be fed into a rate-meter circuit rather than a scaling and timing unit and the output will be derived from an RC network. An analysis, however, of the statistical fluctuations in such a network yields the same general results, the effective counting time being proportional to the time constant of the circuit.

In the interval of time from t to t+dt the charge fed to condenser = q n dt

where n = mean count rate

and q = charge per pulse

the standard deviation of this charge $= q\sqrt{(n\,dt)}$

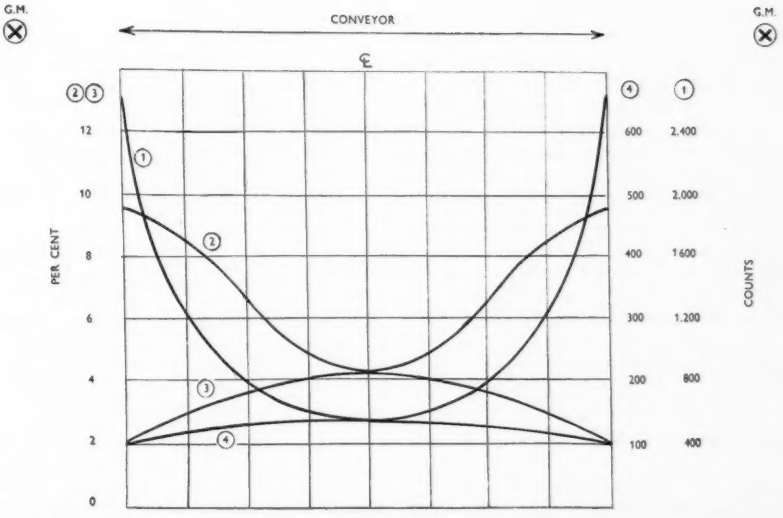


Fig. 3. The effect of moving a point source of radiation across the conveyor belt for the two types of detection system when the pulses from the counters are fed in "series" and "parallel." Curves 1 and 3 refer to the count and standard deviation in the addition system. Curves 2 and 4 refer to the reciprocal system.

at a time t_1 this will have reduced to $q\sqrt{ndt}\; e^{-(t_1-t)/RC}$

The total standard deviation therefore on the output at time t_1 is given by

$$\sigma_q^2 = \int_{-\infty}^{t_1} q^2\, n\, e^{-2(t_1-t)/RC}\, dt$$

$$= q^2 \frac{n\,R\,C}{2}$$

The total charge $Q = q\ n\ RC$

hence the relative standardard deviation $= 1/\sqrt{(n\ 2RC)}$

Fig. 4 shows two basic integrating circuits where in (a) the output voltage is an exponential function of the input count and (b) the response is linear.

Although the value of the voltage fluctuations will differ in the two cases the standard deviation can be related to the input count rate by taking an integration time of 2 RC. Fig. 5 is a series of curves for various time constants and input count rates using a ratemeter as in 4(b) feeding a recorder.

In addition to the statistical fluctuations in a given result there may be errors caused by random or regular drifts in the sensitivity of the apparatus. Differentiation between the two can be a matter of some difficulty. If the detector is known to be receiving a constant amount of radiation then the statistical analysis of its output should follow a Poisson distribution and any marked deviation from this distribution will be the result of mal-functioning of the apparatus and either due allowance can be made or alternative measures taken to eliminate or compensate for the errors. If, however, it is required to determine variations in count rate with time then errors in the sensitivity of the detector will have the same effect on the output as the genuine signals, unless the change of count rate with time is known to follow an exact law (such as a simple decay curve). On the other hand fluctuations in the later parts of the detection circuits may not be subject to the same time constant effect and a limited amount of discrimination

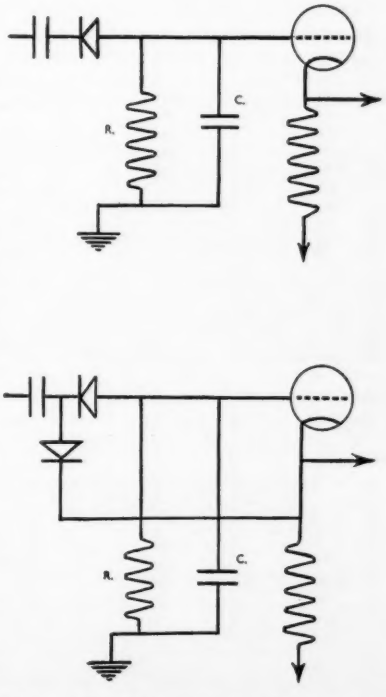


Fig. 4. Simplified ratemeter circuits where in the first the output is an exponential function of the input rate and in the second a linear function.

can be effected; for example sudden jumps in the output of a rate meter which may be due to dry joints, noisy components, etc. This of course assumes that a fair measure of interpretation of the results can be made by skilled operators (Fig. 6). For automatic apparatus, however, this is not possible and spurious signals in the electronics will inevitably have the same effect as changes in the incoming radiation.

Even if the apparatus is working perfectly trouble may be encountered in the variations in the background count. This may be due to genuine changes in cosmic radiation or may arise as a result of extraneous sources being moved in the vicinity, or varying amounts of shielding being interspersed between fixed sources and the detector.

Where very low levels of counting are necessary some measure of compensation for variations in this background can be made with subsidiary detectors, anti-coincident systems or gating circuits which will reject signals lying outside the mean by a given number of standard deviations. Providing a large amount of time for obtaining the result is available a statistical analysis will show the accuracy that has been obtained, but frequently accuracy, which will be expressed again as a standard deviation related to the obtained result needs interpretation in terms of "goodness." This may apparently be a subjective process which is related only to the importance of the individual results but fundamentally this must again relate to the probability of being wrong. For example, if a particular result is one of a series then a certain amount of discretion is

La Statistique des Mesures de Radiation

La vitesse et la précision auxquelles une mesure peut être effectuée en employant des techniques de radiation sont fréquemment limitées par les fluctuations statistiques du taux de radiation décelée. L'importance de ces fluctuations est discutée en termes de la déviation standard d'un dénombrement et la probabilité d'une erreur s'étant glissée dans une mesure quelconque. La déviation standard d'une mesure dans laquelle les dénombrements du N sont enregistrés est simplement de $\sqrt{N}$. Par suite de la désintégration intermittente de la source, des mesures qui sont fonction d'un nombre de dénombrements indépendants sont sujettes à des fluctuations qui peuvent être calculées des déviations standard individuelles. Un exemple est donné par un système d'analyse de minerai où les dénombrements de deux compteurs sont ajoutés "en série" et comparés avec le résultat obtenu lorsqu'ils sont pris "en parallèle."

Bien que d'autres facteurs peuvent influencer la valeur d'un relevé particulier, on appuie sur la nature statistique inhérente de cette évaluation, même lorsque l'analyse statistique a été remplacée par des méthodes intuitives.

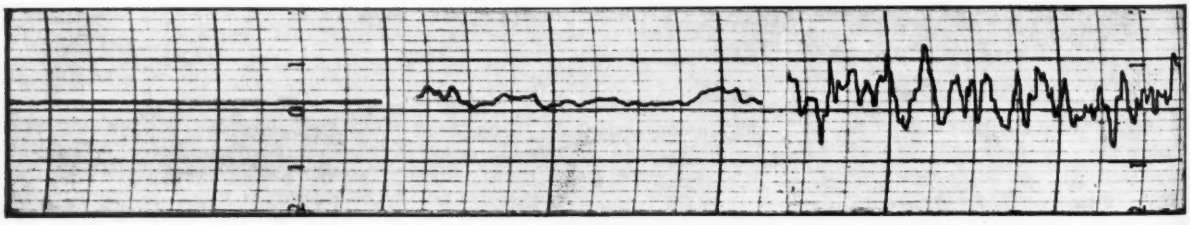
Die Statistik der Strahlungsmessungen

Die Geschwindigkeit und Genauigkeit, mit welchen man Messungen machen kann, bei welchen man die Strahlungstechnik anwendet, werden häufig durch statistische Schwankungen in der Höhe der gefundenen Strahlung begrenzt. Die Grösse dieser Schwankungen wird in Bezug auf die normale Abweichung bei einer Messung diskutiert, ferner die Wahrscheinlichkeit eines Fehlers bei einer bestimmten Messreihe. Die normal Abweichung einer Messreihe, bei der N Messungen aufgezeichnet werden, ist $\sqrt{N}$. Infolge der ganz ungleichmässig von der Quelle ausgehenden Strahlung sind Messungen, die als Funktion von unabhängigen Einzelmessungen sich ergeben, Schwankungen unterworfen, die man aus der normalen Abweichung bei der einzelnen Messung errechnen kann. Als Beispiel wird ein Erzprüfungsverfahren angeführt, bei welchem Messungen mit zwei Zählrohren gemacht werden, deren Ergebnisse "in Reihe" addiert werden and dann mit dem Ergebnis verglichen werden, wenn sie "in Parallelschaltung" gemacht werden.

Wenn auch noch andere Faktoren den Wert einer bestimmten Ablesung beeinflussen können, so muss doch die statistische Natur, die einer solchen Prüfung eigen ist, betont werden, sogar auch dann, wenn mathematische Analyse durch intuitive Methoden ersetzt wird.

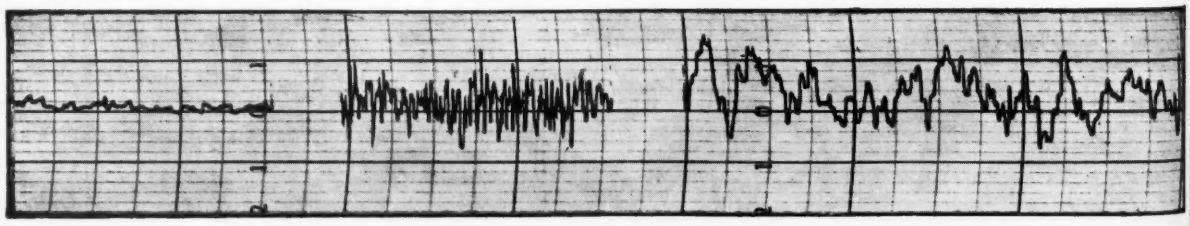
Estadósticas de Medida de Radiación

La rapidez y exactitud con que se puede hacer una medición por medio de la técnica de radiación son limitadas a veces por las fluctuaciones estadísticas en la medida de la radiación comprobada. Se discute la magnitud de estas fluctuaciones en terminos de la desviación normal de un recuento y la probabilidad de que una medición cualquiera pudiera estar equivocada. La desviación normal de una medición en la cual los ricuentos de "N" se registras simplemente como $\sqrt{N}$. Debido a la desintegración errática del origen, las mediciones que son la función de cierto número de recuentos independientes, quedan sujetas a fluctuaciones que pueden ser calculadas por desviaciones normales individuales. Se toma un ejemplo de un sistema ensayador de mineral en el cual recuento de dos contadores se agregan "en series" y se comparan con el resultado obtenido cuando se hace "en paralelo." Aunque hay otros factores que pudieran influir en el valor de una lectura determinada, se hace hincapié en la naturaleza estadística inherente de esta comprobación aun cuando el análisis matemático haya sido sustituido por métodos intuitivos.



count rate: 500/sec. count rate: 50/sec. count rate: 5/sec.

Fig. 5a. Comparison of the random fluctuations in the output of a ratemeter at three different mean input rates. The output is a linear function of input rate. Time constant 10 secs., chart speed 12 in./hr. Scale 1 mm=2½%.



500c/sec. with T.C. 1 sec. 50 c/sec. with T.C. 1 sec. 5 c/sec. with T.C. 10 sec.

Fig. 5b. Comparison of the random fluctuations for different count rates and time constants. Chart speed and scale as above. Apparent differences between recordings of the same T.C.x count rate is caused by relative differences in chart speeds.

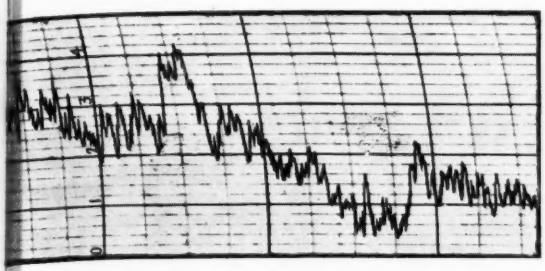


Fig. 6. This record is known to be of a system measuring a varying mean count rate shown by the small excursions but including three sudden changes in sensitivity. Superimposed is a steady downwards drift and small statistical fluctuations.

permissible in rejecting those that appear out of the general run. It is assumed that the results do not lend themselves to a mathematical analysis and reliance is being placed on experience, but the experience is nevertheless an instinctive (or possible inductive) assessment of the chances involved.

If however a limited time is available and, say, a single result only can be obtained then the chances of being wrong are weighted by other considerations and their relation to future measurements. This again is a process of instinctive statistical analysis. If the background count is known to be 10 per minute and the single assay of a sample gives a count rate of 15 per minute then the chance of this not representing the presence of additional activity is approximately one in five. Clearly if a positive answer implies the expenditure of a large amount of effort and money, then the tendency will be to regard the results as entirely inconclusive and not particularly encouraging. If, on the other hand, this is the assessment of the activity in, say, drinking water the tendency would be to regard the results as strongly indicating contamination.

There is thus no way of avoiding the statistical errors associated with a count or the probabilities of being wrong in one's results. Certain dodges can be employed to, say, speed up the time required to take readings by artificially reducing the time constant whilst the reading is building up, but the final result can only be determined in terms of the statistical fluctuations inevitably inherent in the count rate and the effective counting time interval.

In a subsequent article the limitations imposed by statistical fluctuations will be discussed with particular reference to typical types of industrial equipment.

Engineering Features of Calder Hall*

The uranium channels are vertical and the cooled gas returning from the heat exchangers passes up through the graphite core, rising about 200°C in temperature, and passes out to the heat exchangers by four separate 54-in. diameter ducts. On passing down through the heat exchangers, heat is transferred from the gas to the water and steam. The cool gas is returned to the reactor by four 1,500 h.p. centrifugal type circulators, one to each circuit.

Shielding for the reactor is provided by 6-in.-thick mild steel plates and a conventional concrete shield. The plates are mounted a few inches from the main concrete shield which is on the average 7 ft. thick.

The reactor vessel has to contain a graphite core which with its surrounding graphite reflector is between 30 and 40 ft. in diameter. The maximum thickness which at that time it was considered reasonable to weld, at the construction site, to X-ray standards, was taken to be 2 in. For a vertical cylindrical vessel with ellipsoidal ends this permits a working pressure of approximately 100 p.s.i.

After the vessels were completely welded they were surrounded by thermal insulation and stress relieved. The method used was to pass a heavy current through an internal network of tubing as a large heater element with an input of 1.5 megawatts.

Two mobile machines for charging elements, and two for discharging, are provided with each reactor, and each machine carries within it a removable magazine or basket which contains side by side a sufficient number of elements to fill four channels. Each machine is electrically propelled and carries a winch unit for raising and lowering the elements. The winch is driven by a reversing motor having a wide range of variation in controlled speed, thus permitting an operating speed of 175 ft. per minute (90 cm./sec.) along with creep speeds at the extremities of the motion. All motions on each machine are controlled by the operator who rides on it in a seated position with grouped control levers and indicators.

The shut-off mechanism for Calder Hall embodies an electro-magnetic clutch to permit the rod to be dropped at will. A slow speed high-torque motor must, therefore, be used and this called for special development to satisfy the conflicting requirements of high torque, low inertia and minimum size.

During the initial fall of the rod, a high acceleration is desirable to obtain a rapid entry of the rod into the core and hence large neutron absorption and at the end of the travel a low speed is necessary. These requirements were met by the use of an adjustable magnetic shunting system operated by the rod travel which gave the correct torque/speed characteristic at every point during the fall of the rod.

The basic principle of faulty fuel element detection is that of taking a small sample of the coolant gas from each of the uranium channels in turn, and monitoring this sample for radioactive components. If the reactor is free from any radioactive contamination then the sample of gas will not contain any radioactive particles, but as soon as a pin-hole appears in a uranium fuel element then fission products can escape and if the pin-hole develops, uranium oxide may become entrained as well. A proportion of these gaseous fission products have quite short half lives so they soon decay, forming solid particles which can be deposited on a thin wire by electrostatic precipitation. The wire is moved from the precipitation chamber and monitored by a counter.

At Calder Hall the emphasis is on production of plutonium rather than of electricity and the maximum thermal output from a given investment of fuel is desirable. High and low pressure steam is generated at 200 p.s.i. and 60 p.s.i. the optimum not for maximum station thermal efficiency but for maximum generation of electricity together with maximum production of plutonium. Automatic welding equipment already available enabled approximately one hundred million studs to be attached to the tubular surface of the heat exchangers.

Each of the four heat exchangers are connected to the main reactor vessel by 54 in. circular gas ducts and the main circulators are installed in the low temperature return from the heat exchangers to the boilers.

Reactor start-up and partial load conditions required a large variation in the circulator speed and the ability to run at a reduced speed for long periods. While perhaps, operation may show it extravagant it was decided to design for a 10:1 speed variation over the working range of the circulator and to use a D.C. motor direct drive, operating on the Ward Leonard system.

Two turbo alternators are associated with each reactor unit. When the set is operating at rated load there is a supply of steam from the boiler at a pressure of 185 p.s.i. and temperature 590°F and a further supply at a pressure of about 40 p.s.i. and temperature 340°F which enters the turbine after the 15th stage. These two supplies are taken to separate high-pressure and low-pressure steam chests, each of which contains an emergency stop valve and a governor valve.

*Abstract of a Paper presented at the World Power Conference by R. V. Moore et al.

Mechanical Contactors for Liquid-Liquid Extraction

PART 1

For the purpose of this article, mechanical contactors have been classified into horizontal and vertical types, and subdivided into pulse and reciprocating mechanisms. Extraction efficiencies and general advantages and disadvantages of the various types are discussed.

by

J. D. THORNTON, Ph.D., F.R.I.C., A.M.I.Chem.E.

Chemical Engineering Division, A.E.R.E., Harwell

DURING the past 30 or 40 years the use of liquid-liquid extraction processes for the separation of multi-component mixtures has grown in importance until today it is applied to such diverse processes as acetic acid recovery, refining of animal, petroleum and vegetable oils, the separation of antibiotics from fermentation liquors, and the separation of isomers such as meta and para cresols and ortho and para chlornitrobenzenes.[26] In the nuclear energy field, liquid extraction techniques have been developed for the separation of uranium and thorium from their ores as well as for the processing of uranium slugs in which plutonium and uranium are separated from each other and from the bulk of the fission products. In addition similar processes have also been developed for separating U_{233} from irradiated thorium metal.[4]

Although liquid extraction processes are becoming more widespread in their applications, they are not to be regarded as being in any sense competitive with distillation, as each process has its own particular field of application. Thus, whilst distillation by its very nature is confined to the separation of volatile compounds, liquid extraction can be used to effect a separation between non-volatile compounds or those which have similar boiling points or which exhibit azeotrope forming properties.

The use of liquid extraction for the separation of multi-component mixtures involves the partitioning of two or more solutes between two substantially immiscible solvents and such processes in general require a greater number of theoretical stages than is necessary for the extraction of a single solute. In such cases it is often advantageous to use some form of mechanical contactor as opposed to a conventional packed tower, as the enhanced turbulence in such an extractor gives rise to a greater extraction efficiency which in turn enables the size of unit required for a given separation to be reduced considerably. This is particularly important in the nuclear energy field as under such conditions it becomes possible to effect considerable economies in building as well as in biological shielding costs. Thus for the processing of enriched uranium slugs at Oak Ridge, pulsed columns 2.5 in. to 10 in. diameter and 20 ft. to 40 ft. high were used for separating plutonium, uranium and fission products. Using T.B.P. dissolved in a kerosene type hydrocarbon as solvent, separation factors of the order of 10^5-10^6 were obtained for the separation of the uranium and plutonium from the fission products.[14]

In this article mechanical contactors have been classified depending upon whether they are arranged vertically or horizontally and upon whether the dispersion of one phase in the other is effected by a rotary or reciprocating mechanism. The latter distinction becomes important in the case of corrosive or radioactive systems, as vertical rotary column type contactors invariably require internal bearings or mechanical seals which pose difficult maintenance problems.

A number of known contactors have been classified on this basis and the design and construction of representative types such as rotary[18,29] and pulsed columns[33,34] and horizontal pulsed mixer-settlers[35] will be considered in Part II with special reference to the processing of radioactive materials. The pulsed mixer-settler is a new type of contactor in which pulsed ejectors are used to produce the phase dispersion in place of the conventional type of mixing impeller. This is possible as it has been shown[35] that a pulsed ejector will function as a pump and can therefore be used to disperse the heavier phase in the lighter phase by pumping the former through suitably designed spray nozzles. Such a contactor has obvious advantages over the conventional mechanical type of mixer-settler as all mechanical drives are eliminated and a single pulsing unit can be designed to operate a large number of mixer-settlers. In addition the pulsing unit can be located externally to any radiation shielding, thereby reducing the problem of maintenance to a minimum.

Factors Affecting Extraction Efficiency

When a solution containing one or more solutes is brought into contact with a second substantially immiscible solvent, solute distribution takes place between the two phases until equilibrium conditions are reached. The design of extraction equipment is concerned with the rate at which such processes occur and hitherto mass transfer data have been widely interpreted in terms of the Whitman two-film theory.[37,38] It is, however, now recognized that this theory is in fact an over-simplification of the transfer process but nevertheless it provides a convenient basis for the correlation of experimental data. Provided that the over-all mass transfer coefficient is known for a particular system, it is possible to calculate the rate of solute transfer under given conditions.

Before discussing high efficiency contactors in detail it is of interest at this stage to consider the factors which govern the rate of mass transfer. On the basis of the two-film theory it is assumed that mixing by convection in the bulk of each phase is so rapid that concentration gradients are absent and furthermore that on each side of the interface there are static films which are free from convective forces. Thus, in the case of a system consisting of two immiscible liquids with a solute (A) dissolved initially in one of the phases, it is apparent that the rate of mass transfer will be governed by a molecular diffusional process through the interfacial films.

Thus, the rate equation can be written:

$$\frac{N_A}{\theta} = k_1 S(c_1 - c_{1i}) = k_2 S(c_{2i} - c_2) \qquad (1)$$

where k_1 and k_2 are the individual film mass transfer coefficients for phases (1) and (2) respectively. In terms of over-all coefficients, this can be written:

$$\frac{N_A}{\theta} = K_1 S(c_1 - c_1^*) = K_2 S(c_2^* - c_2) \qquad (2)$$

This expression relates the rate of mass transfer to the over-all mass transfer coefficients K_1 and K_2, the interfacial area of contact S and the driving force. Inherent in this expression is the assumption that true equilibrium conditions exist at the interface itself. Equation (2) however cannot be used directly for evaluating the performance of a contactor as the interfacial area of contact between the phases is not normally known. In practice this difficulty can be overcome by writing

the interfacial area term S in terms of the product of the contactor volume V and the specific area a, defined as the interfacial area per cu. ft. of contactor volume ($ft.^2/ft.^3$) thus:

$$N_A/\theta = K_1a.V.\triangle C_m \quad (3)$$

from which

$$K_1a = \frac{N_A/\theta}{V.\triangle C_m} \quad (4)$$

A similar expression can also be written in terms of K_2a for the second phase. In equation (4) the product K_1a is known as the over-all volume mass transfer coefficient and it is in terms of this quantity that the performance or extraction efficiency of a contactor can be assessed. In this expression the term $\triangle C_m$ is the logarithmic mean driving force taken over the concentration range involved, which in the case of a column type contactor is the logarithmic mean of the driving force at the inlet and outlet of the unit.

The over-all volume coefficients K_1a and K_2a based on phases (1) and (2) respectively can be related to the film coefficients by the well-known equations:

$$\frac{I}{K_1a} = \frac{I}{k_1a} + \frac{I}{H.k_2a} \quad (5)$$

$$\frac{I}{K_2a} = \frac{I}{k_2a} + \frac{H}{k_1a} \quad (6)$$

In cases where the equilibrium curve is linear, H is defined as the partition coefficient of the system. These expressions will be referred to later and are of value, under certain conditions, for assessing the relative importance of the two film resistances.

It is apparent from equation (4) that the rate of mass transfer is directly proportional to K_1a which in turn is related by equation (5) to the individual film coefficients k_1 and k_2 and the interfacial area a. Whilst the area is dependent upon the droplet size, k_1 and k_2 would be expected to be a function of those variables which affect the degree of turbulence within the two phases.

In the case of packed extraction towers, it has been shown that the interfacial area is proportional to the dispersed phase flow rate for any given system,[10] provided that the column is operated below the upper transition point, above which droplet coalescence becomes marked. Furthermore the area is independent of the size of packing so long as the latter is above a critical size which is usually of the order of 0.50 in.[17] In this type of contactor, the equilibrium droplet size results from a balance between the interfacial tension forces and the gravitational forces which are proportional to $\triangle\rho$ g; hence the physical properties of the system automatically limit the degree of turbulence and the interfacial area available for mass transfer. It is because of this limitation that liquid extraction processes have in the past been confined to separations which require only a moderate number of theoretical stages.

If, therefore, the extraction efficiency is to be increased it is evident that additional energy must be supplied to the system. This is usually done by subjecting both phases to a rotary or reciprocating motion in such a way that the mechanical work performed upon the system can be controlled. In practice such contactors not only increase the interfacial area but also the degree of turbulence within the system and in the case of rotary and pulsed contactors it has been shown that the principal factors governing the rate of mass transfer are the interfacial area of contact and the diffusional resistance within the droplets themselves. Over a wide energy range the continuous phase resistance is reduced to a low value and can be considered substantially constant.[33]

Although it might be supposed that k_1a and k_2a, and thus K_1a, would increase indefinitely with the energy input this, in fact, is not the case. With rotary and pulsed contactors it has been found that K_1a increases until a limiting value is reached after which there are indications that any further work performed upon the system actually results in smaller values of the over-all coefficient.[33] As the interfacial area term increases progressively it is not unreasonable to suppose that any decrease in the value of K_1a must arise from a corresponding decrease in the dispersed phase film coefficient. This follows from observations of the rate of liquid circulation within falling droplets where it has been shown that if the droplet diameter is reduced below a certain critical size, internal circulation virtually ceases and it behaves hydrodynamically as a rigid sphere.[13] Under these conditions it is probable that any further increase in the interfacial area resulting from a smaller droplet size would be insufficient to offset the slower process of molecular as opposed to eddy diffusion. The critical size at which internal circulation is reduced to a minimum or is virtually non-existent has been correlated for a number of systems in terms of the Bond number $\frac{d^2\triangle\rho g}{\gamma}$ and in general internal circulation only becomes effective when skin friction is a major fraction of the surface forces.

From the design point of view it is not necessary, and in many instances not practicable to adjust the energy input to give the maximum extraction efficiency since in the majority of cases not only would the contactor become uneconomical to operate because of the high power costs, but also because the droplet size would become so small that the free rising velocity and hence the volumetric throughput would become too low for practical purposes. In practice, therefore, some judgment is required in design if extraction efficiency and volumetric throughput are to be optimized to give economic processing.

Hitherto, it has been assumed that the process was one of physical transfer only. In many instances, however, mass transfer is accompanied by a chemical reaction at the interface such as the solvation step which is known to occur in the case of uranyl nitrate solutions:[20]

$$UO_2(NO_3)_2 . 6H_2O + 2S \rightleftharpoons UO_2(NO_3)_2 . 2S . 4H_2O + 2H_2O$$

In such cases, the simple two-film theory is valid only if the chemical reaction is faster than the rate of transport of material to the interface by molecular diffusion. Under conditions of high turbulence such as exist in many types of mechanical contactors, transport of material to the interface takes place by the faster process of eddy diffusion and there is therefore a greater probability of the chemical step becoming the rate-determining factor. In such a case, equations (5) and (6) can still be used to relate the over-all and film coefficients provided that an interfacial resistance term[16] is incorporated on the right hand side.

Characteristics of Mechanical Contactors

In packed extraction columns where the dispersed phase rises or falls by gravity through the continuous phase, the gravitational forces acting upon the droplets are insufficient to prevent droplet coalescence in the higher hold-up regime and therefore if a fine dispersion is to be maintained, additional work must be performed upon the system. With the exception of sonic and ultrasonic methods,[36] which are not described here, the additional energy is usually supplied by mechanical means and a number of types of mechanical contactors have recently been described in the literature.[27] These are summarized for convenience in Table I together with some of their more important characteristics.

Although there is no simple method of comparing the merits of the various contactors shown in Table I, there are two important factors to be considered from the point of view of design, namely the amount of space that any given unit will occupy and the mechanism by which work is performed upon the system. The latter is particularly important where corrosive or radioactive systems are concerned, and more will be said about this later. Accordingly contactors

Table 1: Characteristics of some Mechanical Contactors

Classification	Contactor		Geometry		Energy input mechanism		Method of Settling		Type of Settling		Seals or bearings in contact with process fluids	External pumps required
	Name	Ref.	Vert.	Horiz.	Rotary	Reciprocating	Gravity	Centrifugal	Counter Current	Co-Current		
IA	Rotary annular	18	x		x		x		x		x	
	Rotating disc	29	x		x		x		x		x	
	Oldshue-Rushton	23	x		x		x		x		x	
	Scheibel	30, 31	x		x		x		x		x	
	Bottaro	1	x		x		x		x		x	
	Othmer	24	x		x		x		x		x	
	Schoneborn	32	x		x		x			x	x	
	McKittrick	21	x		x		x			x	x	
	McConnell	19	x		x		x			x	x	x
	*Kiersted	15	x		x		x		x		x	x
IB	Oscillating plate	5	x			x	x		x			
	Mechanically-pulsed column	5	x			x	x		x		x	
	Air-pulsed column	33, 34	x			x	x		x			
	Fenske	9	x			x	x			x		
IIA	Podbielniak	25		x	x			x	x		x	
	Van Dijk	6		x	x		x		x		x	
	Mensing	22		x	x		x		x			
	Edeleanu	7		x	x		x			x	x	x
	Gordon-Zeigler	11		x	x		x			x		
	Holley-Mott	12		x	x		x			x		
	K.A.P.L. mixer-settler	2		x	x		x			x		
	*Pump-settler	27		x	x		x			x	x	x
	Luwesta	3, 8		x	x			x	x		x	
IIB	Mechanically-pulsed mixer-settler	35		x		x	x			x	x	
	Air-pulsed mixer-settler	35		x		x	x			x		

N.B. (1) *Phase dispersion takes place in external pumps.
(2) Class I and Class II contactors refer to vertical and horizontal types respectively.
(3) The letters A and B denote that the phase dispersion is achieved by rotary and reciprocating mechanisms respectively.

have been placed in two main categories depending upon whether they are arranged vertically or horizontally. These are termed Class I and Class II contactors, respectively. Each of these categories has been further subdivided into groups A and B depending upon whether the phase dispersion is produced by a rotating member or by some form of reciprocating mechanism.

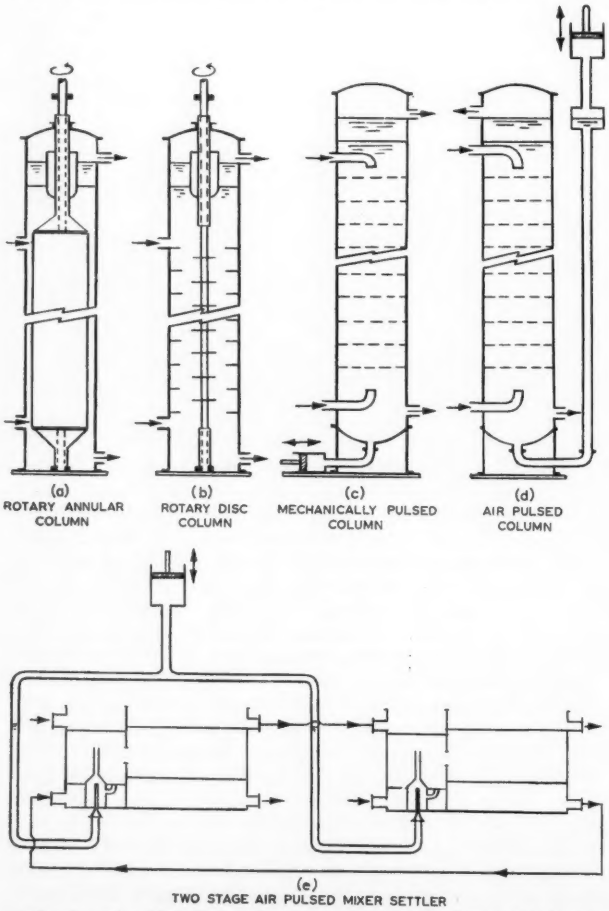


Fig. 1. Class IA contactors are represented by (a) and (b), Class IB by (c) and (d), and the horizontal type Class IIB by (e).

In general, Class IA contactors can be considered as vertical column shells through which the two phases flow countercurrently and in which one phase is dispersed in the other by means of a concentric rotating member of suitable design. A typical contactor of this type is the rotary annular column[18] shown in Fig. 1(a). In some instances, the degree of turbulence in the system is enhanced by means of a system of fixed and rotating baffles as in the case of the rotary disc column[29] shown in Fig. 1(b). At each end of the contactor, suitable calming sections are provided in which the two phases separate under the action of gravity. A limitation common to all equipment of this type arises from the fact that provision must be made to support the rotating shaft. In practice, this means that, depending upon the length of the column, one or more internal bearings must be provided and these will therefore be in contact with the process liquors. Alternatively provision can be made to bring the shaft out through the base of the contactor to an external bearing in which case a suitably designed liquid seal is necessary. However, whichever alternative is adopted, this feature with its associated maintenance problems places a serious limitation upon the use of contactors of this type for handling systems which are highly corrosive or γ-active. It is of interest to note that in the case of the Kiersted contactor, the column shell is in reality a series of superimposed settling chambers, the phase dispersion being carried out in centrifugal pumps located externally to the column. Even so, the dispersion is achieved by a rotary mechanism and therefore the pump seals impose the same limitations as in the case of other IA type contactors.

On the other hand, Class IB contactors in which the droplet dispersion is produced by means of a reciprocating or pulsating motion do not necessarily require liquid seals except in the case of the mechanically pulsed type of unit[5,33] shown in Fig. 1(c). Two general methods of utilizing a reciprocating motion to enhance turbulence and produce droplet breakdown have been used. The first employs reciprocating sieve plates or shafts carrying suitably designed blades as in the case of the oscillating plate column[5] and the Fenske type of contactor.[9] In the second method, the process fluids in the column are themselves subjected to a "pulsing" or reciprocating motion whilst the internal baffles, usually in the form of sieve plates, are attached rigidly to the inside of the contactor

shell. In the latter case, a method of pulsing the column liquors via a pocket of air or inert gas has recently been described[33,34] in the literature which is especially suited to corrosive and radioactive conditions. This contactor, termed an air pulsed column, is shown diagrammatically in Fig. 1(d).

With the exception of the Podbielniak and Luwesta contactors in which the phase dispersion is subsequently settled under the influence of a centrifugal field, Class IIA contactors are variants of the well-known mixer-settler type of unit. In principle an agitator in the form of a suitably designed impeller is located in the mixing chamber and the mixed phases flow co-currently to the settling chamber where the phase separation subsequently takes place. The shafts driving the impellers extend above the level of the liquid in the mixing chambers and no mechanical seals are necessary. It is possible therefore to envisage the use of such contactors for radioactive or corrosive systems, subject to the usual restrictions on materials of construction. However, if the process is one in which a comparatively large number of theoretical extraction stages are required, the advantages accruing from the absence of mechanical seals tend to be offset by the large number of mechanical drives required, and if headroom permits, it is often advantageous to use some type of IB contactor such as the air pulsed column. If, on the other hand, the available headroom is limited and some form of horizontal contactor must be employed, then a type IIB contactor such as the air pulsed mixer-settler[35] is probably the best choice.

The horizontal type IIB contactor in which a reciprocating motion is used to produce the phase dispersion is a new development and is illustrated in Fig. 1(e). Essentially this unit resembles a conventional mixer-settler except for the fact that the mechanically driven impellers in the mixing chambers are replaced by pulsed ejectors. It has been shown[35] that these can function as pumps and therefore, suitably arranged, can be used to disperse the heavier phase in the lighter phase or vice versa. As in the case of the IB types of pulsed columns, the pulsing may be carried out either mechanically or via an air or inert gas pocket, thereby preventing the pulsing unit from coming into direct contact with the process fluids. If a number of extraction stages are required, the ejectors can be connected to a common manifold leading, via the gas pocket, to the pulsing mechanism. Such an arrangement eliminates the multiplicity of mechanical drives associated with IIA type contactors.

There is no way of deciding which type of contactor is the most suitable for a given application except in the light of practical experience. On the other hand it is possible, from general considerations, to select a number of the most suitable contactors as, depending upon the nature of the problem, many of those listed in Table I will be eliminated at the outset on the grounds of limited floor area or height or because such features as mechanical seals render them unsuitable on maintenance grounds.

In an attempt to simplify the selection problem, Pratt proposed an excellent system[28] in which points were allocated to the various contactors in respect of nineteen different design requirements such as the equipment, maintenance and process costs, the number of stages required, the chemical and physical characteristics of the system and limitations on height and floor area, etc. Such a scheme is very comprehensive and is of value when a choice is to be made between a large number of probable contactors. However, in the nuclear energy field, radiation hazards immediately limit the number of contactors that can be employed and as a result the problem of selection is greatly simplified.

From the point of view of the process itself, it can be classified depending upon whether the hazards arise from α-, β- or γ-activity. In the former cases, little shielding is required and maintenance is not a difficult matter. In the latter case, the presence of γ-radiation demands heavy shielding and once the plant has become active it can be a difficult and costly matter to carry out maintenance. For this reason, contactors handling γ-activity should be so designed that moving parts are remote from the process fluids and preferably situated outside the biological shield. Thus maintenance problems can be greatly simplified by using some type of air pulsed system.

Les Contacteurs Méchaniques à Grand Rendement pour les Opérations Liquide-Liquide

En ce qui concerne la protection, des économies considérables peuvent être effectuées en se servant de contacteurs mécaniques dans les opérations d'extraction liquide-liquide. Dans cette discussion générale des qualitiés on a classifié les contacteurs en mécanismes horizontaux et verticaux, les subdivisant en mécanismes pulsatoires et alternifs. On peut calculer l'efficacité d'une extraction en apportant des modifications convenables à la Théorie de deux couches de Whaten. On peut augmenter l'efficacité extractive en augmentant l'énergie fournie aux systèmes jusqu'à un maximum limité, bien que ce maximum coïncide rarement avec le chiffre d'économie maximum. Une discussion des avantages et des désavantages de diverses sortes de contacteurs suit, dans laquelle on fait remarquer qu'à cause de la radioactivité et de la nature corrosive des liquides utilisés, les paliers internes ne sont pas désirables, et on préfère un système pulsatoire ou un système mélangeur-sédimenteur. Il est difficile de prévoir d'une facon précise le système optimum sans expérience pratique des fluides particuliers.

Hochwirksame mechanische Kontakteinrichtungen für flüssig-flüssig Extraktionsprozesse

In der Anwendung von Abschirmvorrichtungen können erhebliche Ersparnisse gemacht werden, wenn man mechanische Kontakteinrichtungen in flüssig-flüssig Extraktionsprozessen benutzt. In der vorliegenden ganz allgemeinen Diskussion der Eigenschaften solcher Kontakteinrichtungen werden sie eingeteilt in horizontale und vertikale, und diese wieder werden unterteilt in pulsierende und hin- und hergehende Mechanismen. Berechnungen des Wirkungsgrades einer speziellen Extraktion können mittels der Zwei-Film Theorie nach Whaten mit gewissen den Verhältnissen angepassten Modifikationen gemacht werden. Die Wirksamkeit der Extraktion kann erhöht werden, wenn man die Energie, die den Systemen zugeführt wird, bis zu einem begrenzten Maximum erhöht; dieses Maximum wird selten mit der Zahl der grössten Wirtschaftlichkeit zusammenfallen. Es folgt eine Diskussion über die Vor- und Nachteile der verschiedenen Arten von Kontakteinrichtungen, in der darauf hingewiesen wird, dass infolge der Radioaktivität und der Korrosionsgefahr Innenlager unerwünscht sind, und daher Einheiten mit pulsierender Bewegung oder nacht Art der Misch- und Absetzvorrichtungen vorgezogen werden. Es ist schwierig, über das beste System eine genaue Voraussage zu bringen, wenn noch keine praktischen Erfahrungen mit den speziellen Flüssigkeiten vorliegen.

Contactores de alta Eficiencia para Procesos de Extracción del tipo Líquido-Líquido

Se pueden hacer considerables economías particularmente en blindaje protector por el uso de contactores mecánicos en procesos de extracción "líquido-líquido." En esta discusión general sobre las propiedades, los contactores han sido clasificados en horizontales y verticales y subdivididos en mecanismos pulsadores y de acción alternativa. Se pueden hacer cálculos sobre la eficiencia de extracción mediante modificaciones adecuadas de la teoría Whaten de dos películas. Se puede aumentar la eficiencia de extracción aumentando la energía suministrada a los sistemas hasta un máximo limitado, aunque este máximo raras veces coincide con la cifra para máxima economía. Sigue una discusión sobre las ventajas y desventajas de varios tipos de contactores, en la que se hace notar que debido a la radioactividad y a la naturaleza corrosiva de los líquidos manejados, son indeseables cojinetes interiores y se favorece un tipo de unidad pulsada o del tipo mezcladorasentador. Es difícil ofrecer un prognóstico exacto sobre el sistema óptimo sin tener experiencia práctica sobre lo fluídos de que se trata.

If such factors are taken into account in conjunction with the characteristics of the contactors listed in Table I, it is possible to formulate a basis for selection which serves as a guide to the probable class of unit most suitable for use under given conditions. Such a scheme is shown in Table II. It must be emphasized, however, that this is not in any way exclusive and the final choice must always be made in the light of practical experience.

On the basis of Table II, the more important contactors are pulsed and rotary columns and the pulsed and K.A.P.L. types of mixer-settlers. Whilst the latter has been described previously, there is a need for more information relating to the construction of the other contactors, particularly with regard to pilot plant units for carrying out preliminary evaluations. In Part II, therefore, constructional details will be given for typical units such as rotary disc, rotary annular and pulsed columns together with a description of the pulsed mixer-settler. Where design information is available, methods of calculating the leading dimensions will also be included.

TABLE II Selection of Contactors for radio-active processing

Design requirements	TYPE OF SYSTEM			
	α β ACTIVITY ONLY		ACTIVITY	
Geometrical requirements	Moderate No. stages required	Large No. stages required	Moderate No. stages required	Large No. stages required
Headroom limited	Types IIA or IIB (1) Air pulsed mixer-settler (2) Mechanically pulsed mixer-settler (3) K.A.P.L. mixer-settler Mensing Edeleanu Gordon-Zeigler Holley-Mott Pump-settler	Type IIB (1) Air pulsed mixer-settler (2) Mechanically pulsed mixer-settler	Types IIA or IIB (without mechanical seals) (1) Air pulsed mixer-settler (2) K.A.P.L. mixer settler	Type IIB (1) Air pulsed mixer-settler
Floor area limited	Types IA or IB (1) Air pulsed column (2) Mechanically pulsed column (3) Rotary disc Oldshue-Rushton Rotary annular	Type IB (1) Air pulsed column (2) Mechanically pulsed column	Type IB (1) Air pulsed column	Type IB (1) Air pulsed column

N.B. (1) refers to the most suitable type of contactor for a given duty.
(2) refers to alternative contactors.
(3) refers to other possible alternatives which might prove to be suitable subject to experimental confirmation.

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Harwell Open Days

From amongst the demonstrations on view to correspondents a few have been chosen to typify the scope of work in hand and the trend of current experiments. Harwell is the centre for atomic energy research in the United Kingdom.

THE week beginning May 28 marked a new phase in the relationship between Government-sponsored atomic energy developments and the general public by the opening of A.E.R.E., Harwell to photographers, who were given tours of inspection followed by a Press conference for a very considerable number of journalists.

With so many visitors involved, the tours were inevitably formalized and exhibitions were staged at various points around the Establishment to compress the significant information into the minimum space and to hinder the usual work of the Establishment as little as possible. Some disappointment was expressed that only a limited amount of normal work was going on in the laboratories which could be seen, but of course this was neither practicable nor even desirable both from the point of view of the reporters and the technicians.

The visit was arranged to mark the end of the first 10 years of development in this country at Harwell and aimed more at giving a general picture of the type of work that the Establishment undertakes than going into detail on certain specific aspects. In his speech of welcome Dr. Schonland gave a brief review of the functions of the Research Group and the Industrial Group and of the power programme to date and probable future developments. Decisions are soon to be taken on the type of reactor to be concentrated upon as the follow-on to the Pippa programme. Two types mentioned as being under consideration were the sodium-cooled, graphite-moderated reactor and the pressurized-water reactor. It is probable that, in the British water-moderated reactors, a clear-cut distinction will not be drawn between boiling and pressurized as present plans envisage a reactor which is virtually a compromise between the two; that is, under steady conditions boiling is only just sup-

pressed in the reactor core but may occur for a limited period during surges in the reactivity or load.

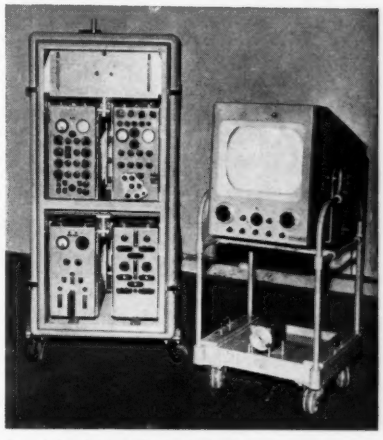
A number of different types of reactor are at present under consideration, the fast reactor experiment at Dounreay which should be operating by mid-1958 being the most advanced in development, and the homogeneous reactor representing, perhaps, the ultimate aim, although fraught with many very serious metallurgical problems.

It is probable that the graphite-moderated CO_2-cooled reactors to be built for the C.E.A.—tenders for the first of which are due by October 1—will be operating at higher power levels than was originally anticipated. No specific figure was given for these power levels but it would not be unreasonable to suppose that a philosophy, not unlike that of the Soviet Union, thinking in terms of 400-MW stations, will be adopted.

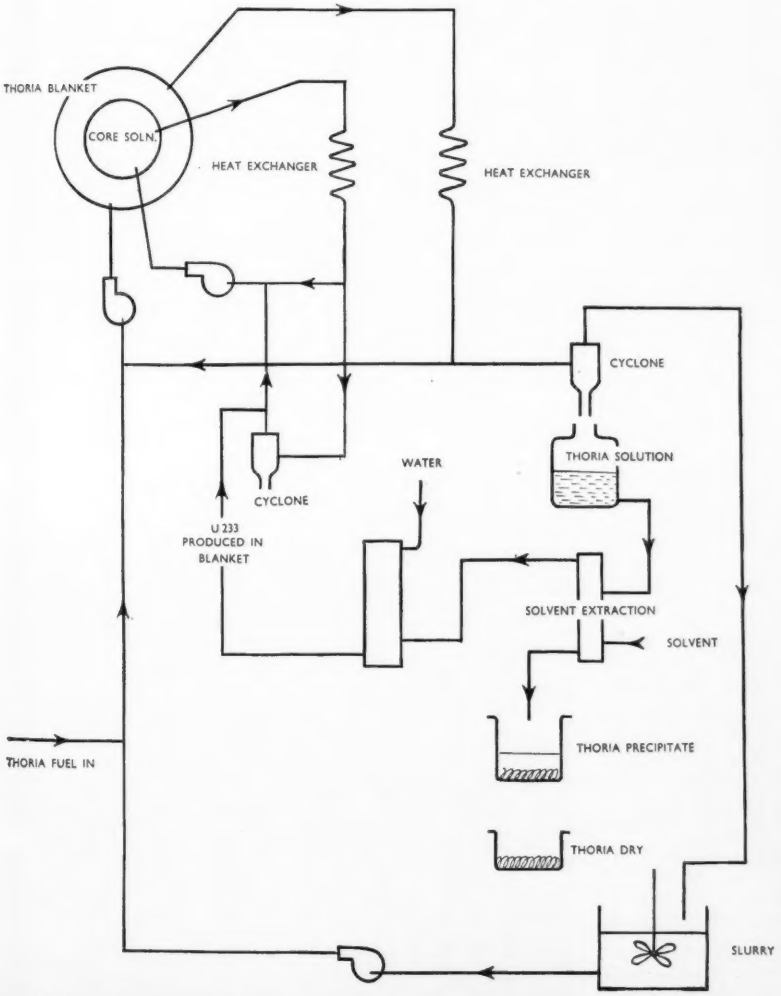
ZEUS

Amongst the reactors which were "open" to public view was ZEUS which has been the experimental reactor devoted to the elucidation of design problems of the Dounreay reactor. Included in the programme of research has been the derivation of the critical loading for Dounreay which has given a figure very close to the theoretical calculations. The critical loading for ZEUS is 1 ton of 25% enriched uranium. The cores of ZEUS and Dounreay are identical but, of course, detailed construction is very different, ZEUS operating on a mean power of approximately 200 watts, which is measured by fission chambers using pulse techniques; Dounreay will use direct current systems.

Experiments are in hand on ZEUS for determining the breeding ratio that can be expected at Dounreay. The major part of the programme on ZEUS is connected with perturbation experiments to allow calculations to be made on the effects of differing canning materials, burn-up and so on. It would appear that these perturbation experiments are of particular value as an extrapolation to bulk changes can be accurate. Experiments on ZEPHYR, for example, have shown that small-scale perturbation experiments can give very accurate results when applied to bulk changes. Two opposing faces of ZEUS have been built to simulate the Dounreay reactor and to allow accurate measurements on shielding.

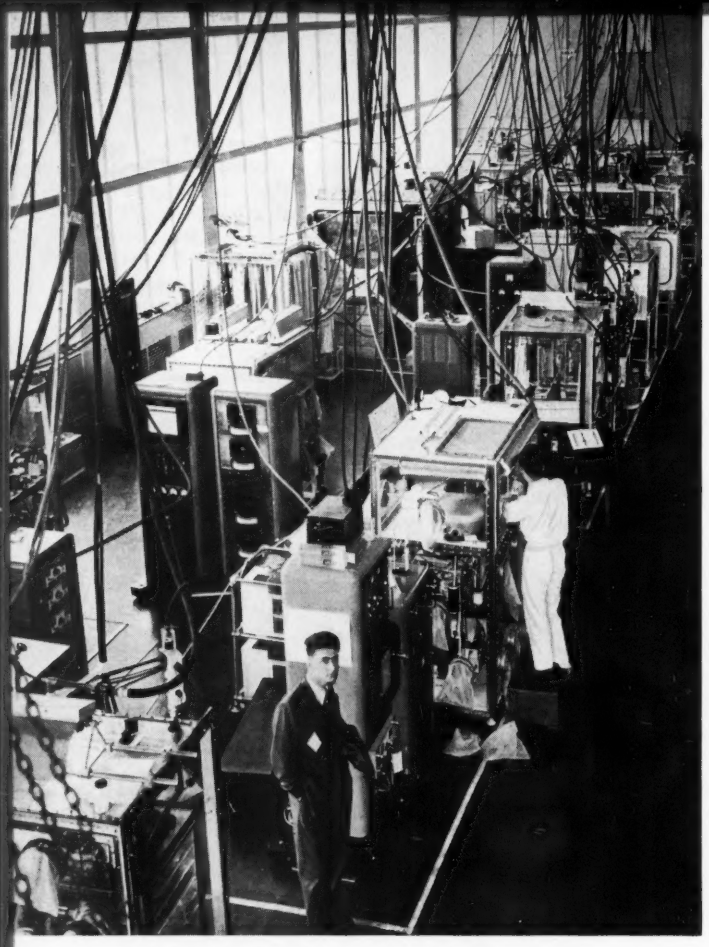


Special closed loop television system for the remote microscopic examination of highly active specimens; made by E.M.I.



Simplified flow diagram of a homogeneous reactor. Blanket slurry and core solution are continuously circulated through heat exchangers, whilst proportions of each are bled off for the U 233 and fission products to be extracted. U 233 is returned to the core to make up spent fuel.

Dry box developed by Western Details of Bristol in co-operation with A.E.R.E. for the thermal analysis of plutonium.



General view of the plutonium laboratory showing a bank of dry boxes. External supplies are fed in from above through isolators to allow the whole box to be removed for decontamination.

ZEUS utilizes the same control system as will be operating at Dounreay with six rods at the top acting as shut-off rods and 3 pairs of rods at the bottom whose functions are safety rods, burn-up compensation rods, and fine control. The middle two are fixed in ZEUS as the burn-up is negligible. Control channels on ZEUS measure the power level and rate of power level change in quadruplicate. Any fault occasioned in any of these channels shuts off the reactor: at Dounreay two faults will be required simultaneously to shut down the reactor but power level and power rate will be supplemented by a multiplicity of channels measuring coolant temperature, coolant flow, external radiation, etc.

DIMPLE

Dimple is a particularly difficult reactor to describe in any general terms. During the visit the reactor was in the process of testing the core assembly that will be used in DIDO, the core being 40 cm. diameter and 60 cm. high. DIMPLE has been specifically built so that a number of lattice arrangements can be tried in a heavy-water moderator, the height of which is used for control. It requires approximately 10 days to change the lattice assembly of which two days at the beginning and end are required for scavenging out the D_2O and drying out the new assembly. Control channels on DIMPLE comprise three power level channels and one rate of rise channel, any one of which will shut down the reactor. There are additional gating circuits, for example, to prevent access to the top face whilst the reactor is operating. A priming source of approximately 10^4n/cm.^{2}-sec. is used when an enriched core is being investigated, but where natural uranium provides the fuel no primer is required. It is interesting to compare with ZEUS, which uses a priming source of 1 curie Ra-Be.

Plutonium Work

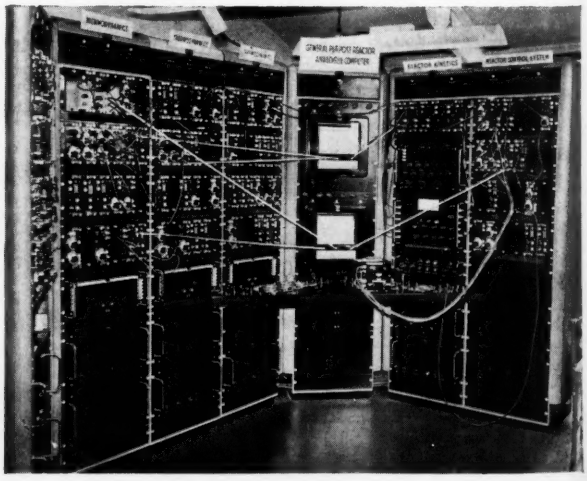
In Building 220, visitors were shown metallurgical investigations on plutonium in progress and the type of dry boxes and enclosed equipment that must be used. It is officially estimated that because of the precautions necessary experiments on plutonium take 5 times as long as those on uranium but experience is slowly bringing this factor down. Visitors were shown in one of the dry boxes a 2-lb. ingot of plutonium which, due to the alpha decay ($1\frac{1}{2}$ watts approximately), is 10° hotter than the ambient temperature. Considerable precautions must be taken in this department not only to maintain safe working operation from the contamination point of view but to ensure that in no circumstances can a critical mass accumulate. Regulations lay down that 2 lb. of plutonium is the maximum that can be worked on in any one box, but in the store room at the end where a large number of individual safes are provided 200 kilograms can be (and have been) stored.

In experiments on this material metallurgists must be able to account for the plutonium used to within 1 milligram. This is nearly impossible in practice but gives an indication of the strictness of the supervision.

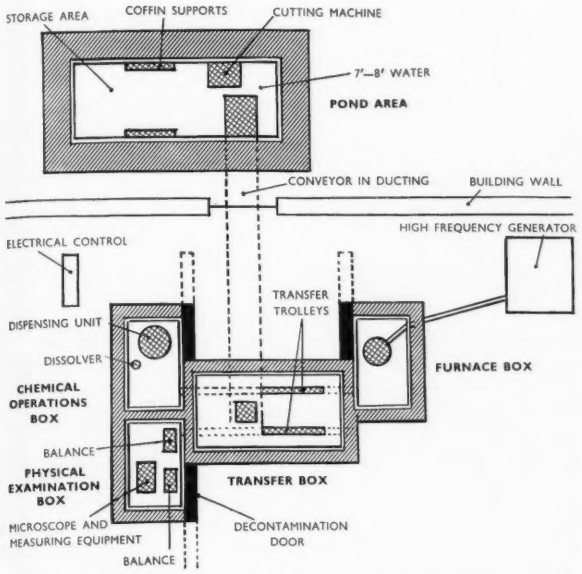
Chemical Engineering

In the Chemical Engineering building visitors were able to see the solvent extraction process similar to that used at Windscale where spent fuel elements are decanned mechanically, dissolved in nitric acid and then fission products and uranium extracted with TBP in kerosene. A number of counter current mixer-settler equipments were shown with demonstrations of the systems adopted for increasing the surface area of contact, such as bubble size reduction by pulsing.

An experimental process for the treatment of activated fuel elements aimed at cutting the cost involved in solvent extraction was open to inspection. In this the element is decanned mechanically and then melted in a graphite crucible at 1,200-1,300°C. A number of the fission products boil off at this temperature and can be collected, while others form a slag which floats to the top and the sides of the melt. The molten uranium can then be run off from the bottom and re-fabricated into fuel elements. The extraction process is by no means complete and although fuel elements are made sufficiently depleted of fission products for satisfactory operation in the reactor they are still highly active. Shielding



Analogue computor designed by A.E.R.E. for work on reactor problems. Sub-units manufactured by Elliott Bros. (London) Ltd.



Layout of experimental unit for the treatment of spent fuel elements by melting in a graphite crucible after mechanical decanning. Re-fabrication of still contaminated uranium must be performed behind shielding.

arrangements are, therefore, required on machining and canning and provision made for shielding whilst charging the reactor. The increased cost in these operations it is hoped however, will not be sufficiently large to prevent the process becoming more economical than solvent extraction. It is hoped to operate the melt on a semi-batch principle.

A number of exhibits demonstrated the methods under examination for treating the core solution of a homogeneous reactor with concentration of fission and corrosion products in cyclone separators. The products tend to conglomerate into particles several microns in diameter. It is hoped to start in-pile experiments on this process shortly.

Remote handling

A group has recently been formed at Harwell to concentrate on the problems of the remote handling of objects and a comprehensive exhibit of extended and articulated handling equipment was on view. An account was given of the difficulty of working continuously with extended tongs fitted through lead balls, particularly when heavy equipment was involved. Air cushioning of the lead balls can decrease effort considerably.

BEPO

In Hangar 10 models of PLUTO, DIDO and LIDO were on view. Apart from its radio-isotope programme and in-pile chemical experiments BEPO is at present testing a liquid sodium, a carbon-dioxide and a light-water loop for the elucidation of problems associated with future reactor coolants.

Liquid Metals

A very small exhibit indicated the types of experiments that were in hand to determine the corrosion properties of molten metals such as sodium, bismuth and lithium. One of the problems associated with the use of these coolants is the possibility of solidification at a cold part of the loop, resulting in a blockage or of preferential corrosion beginning at a particular point resulting in a major break-down. There is a vast programme of work to be undertaken in this field before liquid metal fuels become a practicable proposition.

Journée Publique à Harwell

Pour célébrer son dixième anniversaire, l'Atomic Energy Research Establishment de Harwell a ouvert ses portes au public pendant la semaine du 28 Mai au 1er Juin, et les invités firent la visite de certaines parties choisies de l'établissement. Parmi les exemples de techniques de laboratoire modernes figurait l'aile plutonium du bâtiment de la chimie où tous les travaux sont effectués en boîtes sèches qui peuvent être emlevées en entier pour la décontamination dans un endroit spécial. Un nombre d'opérations difficiles furent montrées en train d'être conduites au moyen d'un appareillage de commande à distance, ou par des hommes complètement renfermés dans des vêtements de protection.

Des systèmes de réacteurs possibles pour l'avenir, et des expériences s'y rapportant, ont retenu particulièrement l'attention. On y trouve un diagramme d'un réacteur homogène simplifié dans lequel la relation de création est telle que le noyau est maintenu critique par de l'U 233 extrait de la couverture. On emploie des cyclônes pour l'élimination des produits de la fission et de la corrosion. Une alternative à l'extraction par dissolvants des produits de la fission est représentée par la fonte d'éléments d'uranium dans un creuset en graphite dans lequel les produits de la fission ou s'évaporent ou montent à la surface sous forme de scories. La fabrication d'éléments de combustible qui s'ensuit demande une protection contre l'activité résiduelle, mais il se pourrait quand même que le prix de revient soit considérablement au-dessous de celui des procédés actuels.

Besichtigungstage in Harwell

Zur Feier des 10ten Jahrestages der Gründung des Kernkraftforschungsetablissements hat Harwell vom 28ten Mai bis zum 1sten Juni eine "offene Woche" abgehalten, in der eingeladenen Gästen ausgewählte Teile des Etablissements vorgeführt wurden. Beispiele der modernen Laboratoriumstechnik wurden in der Plutoniumabteilung im Chemiegebäude gezeigt, wo alle Arbeiten in Trockenkammern ausgeführt werden, die als komplette Einheiten zur Entgiftung auf ein spezielles Gelände gebracht werden können. Eine Anzahl schwieriger Operationen wurde gezeigt, die mit ferngesteuerten Apparaten oder von vollständig in Schutzkleidung gehüllten Personen durchgeführt wurden.

Zukünftig mögliche Reaktorsysteme und Experimente im Zusammenhang mit solchen waren von besonderem Interesse. Es wird eine Skizze gezeigt, in der ein vereinfachter homogener Reaktor dargestellt ist, bei welchem das Brutverhältnis so ist, dass der Kern im kritischen Zustand durch U 223 gehalten wird, das vom "blanket" extrahiert wird. Korrosion- und Spaltprodukte werden durch Zyklone eliminiert. Als Alternative zur Extraktion der Spaltprodukte durch Lösemittel dient das Schmelzen der Uraniumelemente in einem Graphittiegel, in welchem die Spaltprodukte entweder verdampfen oder als Schlacke zur Oberfläche steigen. Die spätere Herstellung von Brennstoffelementen erfordert Schutz gegen bleibende Aktivität, jedoch ist es möglich, dass die Kosten trotzdem beträchtlich niedriger werden als bei den zur Zeit geübten Verfahren.

Dia de Visita en Harwell

Para celebrar el 10° aniversario de su fundación el Establecimiento de Investigación de Energía Nuclear de Harwell, tuvo una semana abierta a los visitantes desde el 28 de mayo al 1° de junio, durante la cual los invitados pudieron ver partes preseleccionadas del Establecimiento. Entre los ejemplos de la moderna técnica de laboratorio mostrados figuró el ala del plutonio en el edificio dedicado a la parte química donde la totalidad del trabajo allí realizado se hace en cajas secas que pueden ser retiradas por completo para su decontaminación en zonas especiales. También se hicieron ciertas operaciones difíciles realizadas por equipo de control a distancia o por individuos recubiertos por completo de ropas protectoras.

De especial interés resultaron los futuros sistemas posibles de reactores y los experimentos con ellos realizados. Se ofrece un dibujo de un reactor homogéneo simplificado en el cual la relación de creación es tal que el núcleo es mantenido crítico por medio del U 233 extraido del colchón. Se emplean ciclones para la eliminación de productos corrosivos y de fisión. Una alternativa para la extracción solvente de los productos de fisión consiste en derretir los elementos de uranio en un crisol de grafito en el cual los productos de fisión se vaporizan o suben a flor en la parte superior como escoria.

Zirconium

PART 3—Properties and Uses

The low neutron cross-section and good anti-corrosion properties make zirconium an important constructional and cladding material. The main physical and mechanical properties are summarized, corrosion resistance is discussed and some notes given on the alloying of the metal.

by
G. L. MILLER, Ph.D., B.Sc., A.R.I.C., M.I.Chem.E.
Director of Research, Murex Ltd., Rainham, Essex

IN general, the corrosion resistance of zirconium is very similar to that of tantalum; it is resistant to all dilute acids and will withstand attack from hot concentrated hydrochloric and nitric acids. Unlike tantalum, zirconium will also resist corrosion by hot concentrated alkalis. When discussing the corrosion resistance of zirconium, it is necessary to point out that the metal contains impurities some of which may considerably reduce the resistance of the metal to attack by certain media. In particular, carbon if present in amounts above about 0.04% renders the metal susceptible to attack and this explains why corrosion resistance data obtained from zirconium samples prepared by melting in graphite should be discounted as representative of present production.

The corrosion resistance of zirconium to water at elevated temperatures and pressures is of particular interest to designers of nuclear reactors. High purity water at elevated temperatures possesses surprisingly severe corrosive properties and rapidly attacks many materials. The attack on zirconium varies with the impurity content; carbon and nitrogen being particularly potent in degrading the metal. The preparation of the surface of the metal prior to testing is very important and it is advisable to remove 1.5 to 2.0 mils of metal from the surface by treatment with a solution of 50% distilled water, 45% concentrated nitric acid and 5% hydrofluoric acid (48%). This treatment yields a specimen with bright, smooth surfaces, ensuring the absence of misleading results due to abrasion effects.

The tests are usually performed in an autoclave using high purity water at temperatures and pressures in the region of 350-400°C. and 1,500 p.s.i.

The reaction between zirconium and water at elevated temperatures occurs in two distinct phases. The first is characterised by the formation of a thin adherent coating. The kinetics of the corrosion reaction may be described by the empirical equation

$$\triangle m = kt^n$$

where $\triangle m$ is the weight gain, t is the time, and k and n are constants for a given temperature. During the initial period the value of n is less than $\frac{1}{2}$, implying effective protective action on the part of the corrosion product. After a time the second and more rapid reaction begins, coincident with the appearance of a non-adherent white corrosion product on the surface of the metal. At this point, usually known as the "breakaway" or "breakdown," weight-gain measurements become unreliable because of spalling but it is believed that the new rate law is linear, that is, n=1. The period before breakdown occurs is largely dependent upon the test temperature and the impurity content of the metal and may vary from a few hours to one year or longer.

The useful life of zirconium in the presence of water at elevated temperatures is measured by the time required to reach the breakdown point and is determined by the amount of the impurities. The main impurities which have been tested are nitrogen, carbon, titanium, aluminium, hydrogen and oxygen.

The effect of nitrogen is very pronounced and samples containing appreciably more than 0.004% tested at 315°C broke down rapidly (Fig. 1); a limit of 0.005% nitrogen has been proposed but production problems are serious, if this level is to be maintained. However the deleterious effect of nitrogen can be counteracted somewhat, depending on the content, by the addition of tin.[4]

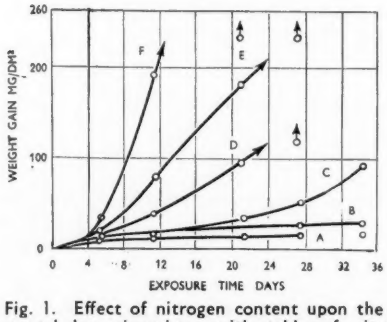
Carbon, like nitrogen, has a very bad effect on the corrosion resistance of zirconium and Fig. 2 indicates that the corrosion rate increases with increasing carbon content and breakdown occurs in a comparatively short time when the carbon exceeds 0.10%. A maximum carbon content of 0.04% has been proposed. As in the case of nitrogen an addition of tin is beneficial in counteracting the effect of the carbon.

Titanium, if present in amounts between 0.1 and 4% is deleterious but below or above these values the metal has good corrosion resistance. As the titanium content can be held to low values without difficulty a maximum of 0.008% has been suggested.

The harmful effect of aluminium is pronounced at concentrations above about 0.10% and a maximum of 0.01% is proposed to ensure good corrosion resistance of the zirconium. As with nitrogen and carbon contamination, tin counteracts the effect.

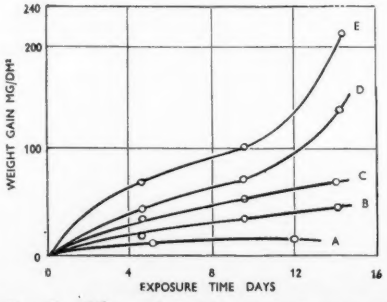
Although the presence of hydrogen was originally not considered to impart any harmful effect, current work indicates that the presence of 0.1% hydrogen causes appreciably faster corrosion than is observed with specimens containing 50 p.p.m. or less.

The presence of up to 0.5% oxygen in zirconium has only a slight effect upon corrosion resistance but at 1%—a value far exceeding that present in ductile metal—the corrosion rate is reported to be seriously affected.



	NOMINAL	ANALYSED
A	30	30
B	40	30
C	50	30
D	70	40
E	80	90
F	140	130

Fig. 1. Effect of nitrogen content upon the corrosion resistance of crystal bar zirconium, with table of nitrogen content in parts per million.



	NOMINAL	ANALYSED
A	300	300
B	700	400
C	1100	600
D	1300	900
E	1500	1000

Fig. 2. Effect of carbon content upon the corrosion resistance of zirconium. Carbon content of samples in p.p.m.

PROPERTIES OF ZIRCONIUM

TABLE 1. Physical Properties.

Melting point	1845 ± 25°C
Allotropic transformation temperature	863 ± 3°C
Specific heat:	
(a) 25-100°C	6.32 cal/mol/°C
(b) αZr 862°C	8.03 cal/mol/°C
(c) βZr 862-1127°C	7.27 cal/mol/°C
Linear coefficient of thermal expansion:	
(a) 20-200°C	5.4×10^{-6} per °C
(b) 20-400°C	6.9×10^{-6} per °C
(c) 20-700°C	8.9×10^{-6} per °C
Thermal conductivity at 50°C	0.04 cgs units
Density at 20°C	6.5 gm/cm³
Electrical resistivity:	
(a) Iodide bar	39×10^{-6} ohm-cm
(b) Kroll bar	48×10^{-6} ohm-cm
Temperature coefficient of resist. (iodide bar)	0.0044 per °C
Modulus of elasticity	13.9×10^{6}
Electrochemical equivalent	0.2363 mg/coul.

Lattice constants	Hexag. close packed (alpha)	Body cent. cubic (beta)
a	3.228A	3.61A
c	5.120A	—
c/a	1.59	—
Interatomic distances		
d1	3.16A	3.12A
d2	3.22A	—

TABLE 2. Mechanical Properties of Commercial Zirconium.*

	Kroll Process†		Iodide Process‡	
	50% cold worked	Annealed 1300°F	Hard drawn	Annealed 1450°F
Ultimate tensile strength	82,600 lb./in.²	49,000 lb./in.²	83,300 b./in.²	35,900 lb./in.²
Proof stress, 0.2% offset	75,400	29,200	69,700	15,900
Proportional limit, 0.01 offset	41,800	16,900	32,100	8,350
Elongation; %			18	31
Modulus of elasticity	12,800,000	13,700,000	14,500,000	11,350,000
Hardness	B-95	B-83	B-87.4	B-30.0
Charpy impact resistance	14.8 ft.-lb.		1.5 to 3.5 ft.-lb.	2.5 to 6.0 ft.-lb.

†Oxygen 0.11%, nitrogen 0.01%.
‡Oxygen 0.04 to 0.06%.

* Impurities in the metal affect the properties: oxygen in particular has a considerable effect on mechanical properties this being the principal reason for the variation in values shown in Table 2.

TABLE 3. Corrosion Properties of Zirconium in Various Mediums.

Medium	Concentration	Temperature	Rating*
Acetic acid	5 to 99.5%	35, 60, 100°C	Excellent
Acetic anhydride	99.5%	139.6°C	Excellent
Aluminium chloride	20, 25, 30%	35, 60, 100°C	Excellent
Aluminium sulfate	10, 30%	Boiling	Excellent
Ammonium chloride	Saturated	35, 60, 100°C	Excellent
Ammonium hydroxide	28%	Room, 100°C	Excellent
Ammonium sulfate	Saturated	50°C	Excellent
Aniline hydrochloride	5, 20%	35°	Excellent
Aqua regia	3 HNO_3 to 1 HCl	Room	Poor
Barium chloride	20%	35, 60, 100°C	Excellent
Calcium chloride	20, 30, 50%	20, 50, 100°C	Excellent
Carbon tetrachloride,	100%	Room 50°C	Excellent
Carbon tetrachloride chloroform, ethylene dichloride, trichloro-ethylene, tetrachloro-ethylene, tetrachloro-ethane		Boiling	Excellent
Chlorine (saturated with water)		Room	Poor
Chlorine (water saturated with chlorine)		Room	Good
Chlorinated hydrocarbon-water mixture		Boiling	Excellent
Chromic acid	10, 20, 30%	20, 50, 100°C	Excellent
Citric acid	10-50%	35, 60, 100°C	Excellent
Cupric chloride	1-20%	35°C	Excellent 1%, Fair 2.5%, Poor 5-20%
		60°C	(Good 1%, poor 2.5-20%)
		100°C	Poor
Dichloroacetic acid	100%	100°C	Fair-poor
Ethyl alcohol	95%	78.4°C	Excellent
Ferric chloride	1-30%	35-60°C	Excellent 2.5%, Good 5-10%, Poor 15-30%
		100°C	Excellent 1%, Good 2.5%, Poor 5-30%
Formic acid	10-90%	35, 60, 100°C	Excellent
Furfuryl alcohol		169.5°C	Excellent
Hydrochloric acid	0-20%	35, 60, 100°C	Excellent

Medium	Concentration	Temperature	Rating*
Hydrogen peroxide	10%	50°C	Excellent
Lactic acid	10-85%	35, 60, 100°C	Excellent
Manganous chloride	20%	35, 60, 100°C	Excellent
Magnesium chloride	42%	35, 60, 100°C	Excellent
Mercuric chloride	1% saturated	35-100°C	Excellent
Methyl alcohol	99%	65°C	Excellent
Monochloroacetic acid	100%	100°C	Excellent
Nickel chloride	20%	35, 60, 100°C	Excellent
Nitric acid	10%-conc.	19-100°C	Excellent
Ocean water		35°C	Excellent
Oxalic acid	0.5-25%	35, 60, 100°C	Excellent
Phenol (carbolic acid)	25, 50, 100%	20, 50°C Boiling	Excellent
Phosphoric acid	5-85%	35°C	Excellent
		60°C	Good
		100°C	Excellent 5-10%, Good 30-60%, Poor 65-85%
Potassium hydroxide	10-40%	Room, 100°C	Excellent
Propylene oxide	100%	34°C	Excellent
Red fuming nitric acid	92% HNO_3, 6.5% NO_2, 1.5% H_2O	Room	Excellent
Sodium chloride	Saturated	35, 60, 100°C	Excellent
Stannic chloride	24%	35, 60, 100°C	Excellent
Sulphuric acid	10-96.5% aerated	35-60°C	Excellent 10-70%, Poor 75-96.5%
		100°C	Good 10-70%
Sulphuric acid + nitric acid	H_2SO_4=0-1.0 HNO_3 0-0.11	60°C, 100°C	Excellent
	0.5	35°C	Poor
	0.25	60°C, 100°C	Poor
Sulphurous acid	6% SO_2	100°C	Excellent
Tannic acid	25%	35, 60, 100°C	Excellent
Trichloroacetic acid	100%	100°C	Poor
Trisodium phosphate	5, 20%	35, 60, 100°C	Excellent
Uranyl sulfate	U, 40 g/litre	250°C	Excellent†
White fuming nitric acid		Room-160°F	Good
Zinc chloride	20%	35, 60, 100°C	Excellent

*Corrosion rates of less than 0.05 mil/year are rated excellent; 0.05 to 5, good; 5 to 10, fair; over 10, poor.
†Iodide zirconium.

Other impurity elements which are harmful if present in sufficient amount are calcium, magnesium, chlorine, and silicon. These elements are usually present in amounts less than the following: calcium, 0.0025%; magnesium, 0.0020%; chlorine, 0.0015%; and silicon, 0.0020%. Hafnium, copper and tungsten are inocuous at the usual impurity level, whilst iron, chromium and nickel are beneficial.

The effect of tin additions on the corrosion resistance of zirconium containing 60 p.p.m. of nitrogen is shown in Fig. 3: it will be noted that there is an optimum tin content which is dependent on the nitrogen content of the zirconium. The addition of tin is not the final solution however, but if iron is added to the binary alloy then satisfactory results are obtained as is shown in Fig. 4. Nickel and chromium also behave in the same manner as iron.

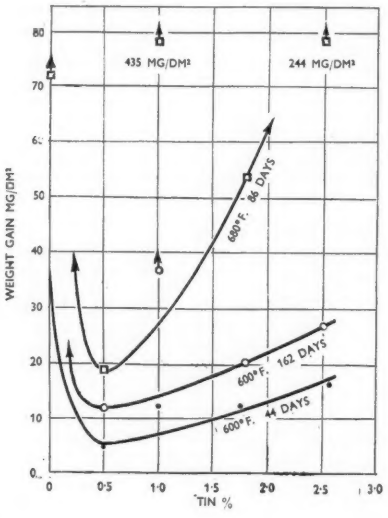


Fig. 3. Effect of tin content on the corrosion resistance of arc-melted sponge base zirconium alloys.

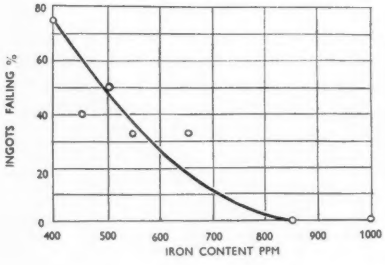


Fig. 4. Effect of iron content on the incidence of breakaway corrosion on specimens from ingots of crystal-bar 2.5% tin alloy. Test conditions were 600°F water and 68-day exposure.

On the basis of the work on the effect of tin, iron, chromium, and nickel additions to zirconium, an alloy termed "Zircalloy-2" was produced specially for nuclear operations. This is a complex alloy of sponge zirconium containing 1.5% tin, 0.12% iron, 0.10% chromium and 0.05% nickel (and a maximum of 60 p.p.m. of nitrogen, 50 p.p.m. of aluminium, and 50 p.p.m. of titanium) which has found extensive application in water-cooled nuclear reactors. The discovery of this alloy has made it possible to use zirconium produced by the Kroll process without the expensive iodide purification treatment.

Variations of tin content from 0.07 to 1.5% have no effect on corrosion rate. Variation of the summation of iron, nickel and chromium from 0.10 to 0.5% shows a slight improvement with increasing amounts in 400°C steam, whereas in 360°C water, optimum corrosion resistance appears at a 0.30% level. Nitrogen content of "Zircalloy-2" may be as high as 0.01% without adversely affecting corrosion resistance.

In view of the above discussion on impurity levels, it is interesting to note the specification for reactor-grade zirconium offered by the Carborundum Metals Co. Inc. who are producing metal for the U.S. Atomic Energy Commission.

TABLE 4. Specification for Reactor Grade Zirconium.

	Sponge: % maximum	Ingot: % maximum
Al	0.01	0.01
Cl_2	0.06	—
Cr	0.01	0.01
Fe	0.10	0.10
Mg	0.06	0.005
Mn	0.01	0.01
N_2	0.01	0.01
Ni	0.007	0.007
Pb	0.005	0.005
Ti	0.005	0.005
B	0.0001	0.0001
V	0.005	0.005
C	0.06	0.06
Hf	0.02	0.02

Brinell hardness (3000 kg load-10 mm ball) 150 max.

The main interest in zirconium at the present time is as a structural material for nuclear reactors because of its low cross-section and its relatively good strength at moderately elevated temperatures.

The absorption cross-section of hafnium-free zirconium (0.18 barns) is much lower than that of constructional metals such as iron (2.43 barns), nickel (4.5 barns) or copper (3.59 barns). It compares favourably with aluminium (0.125 barns) and magnesium (0.059 barns) and has better high strength and corrosion resistant properties than either. It was disclosed at

PROPERTIES OF ZIRCALLOY-2*

TABLE 5. Mechanical Properties.

1. Tensile.

Temperature		Strength, 10^3 lb./in.²		RA, %	Elongation in 2 in., %
°F	°C	Yield (0.2%)	Tensile		
RT	RT	44.8	68.6	36	22
500	260	18.3	31.9	58	36
900	480	10.5	22.1	58	36

2. Effect of Cold Work.

Cold work %	Strength, 10^3 lb./in.²		RA, %	DPH
	Yield (0.2%)	Tensile		
Hot rolled	66.2	82.6	42	210
10	81.1	92.2	38	228
25	90.6	103.8	37	231
40	98.5	108.0	36	243
60	102.1	110.2	35	256

3. V-notch Charpy Impact Strength at Room Temperature: 6 ft.-lb. (aged); 55 ft.-lb. (quenched)

4. Creep Rate at 650°F (345°C):
$\log u = -9.75 + 0.215S$ for $14 < S < 27$
$\log u = -246.95 + 9.0S$ for $27 < S <$ tensile strength
(u in in./in./hr.; S in 10^3/lb./in.²)

5. Fatigue Endurance Limit at 600°F (315°C): 28,000 lb./in.² (unnotched); 9,000 lb./in.² (notched)

6. Modulus of Elasticity: 13.8×10^6 lb./in.²

TABLE 6. Hot-Water Corrosion Properties.

550°F (290°C) water: $\log \triangle m = 0.50 + 0.30 \log t$

600°F (315°C) water: $\log \triangle m = 0.74 + 0.26 \log t$

680°F (360°C) water: $\log \triangle m = 0.76 + 0.38 \log t$ (up to 112 days)

750°F (400°C) steam (1500 lb./in.²): $\log \triangle m = 1.10 + 0.32 \log t$ (up to 41 days)

($\triangle m$ = weight gain, mg/dm²; t = time, days)

*Zircalloy-2 is prepared to the following specification: 1.2 to 1.7% tin; 0.07 to 0.20% iron; 0.05 to 0.15% chromium; 0.02 to 0.08% nickel.

the Geneva Conference that a water-cooled graphite-moderated reactor built in the U.S. required enrichment of the fuel to only 0.92% uranium-235 compared to 2.5% U_{235} for a Russian reactor of similar design using stainless steel pressure tubes and fuel cans.

As a cladding material for uranium fuel elements zirconium has a number of advantages. The absence of inter-metallic compounds or low melting phases or eutectic alloys and the complete solubility in body-centred cubic range makes the attainment of a complete metallurgical bond and therefore good heat transfer feasible in zirconium-uranium couples.

The compatibility of zirconium and uranium was discussed in a recent paper[5] in which the penetration of liquid uranium alloys into the walls of a container was measured at various temperatures. It was concluded that zirconium, as well as magnesium, niobium and molybdenum, is effectively inert to uranium up to 600°C.

In the same paper the compatibility of zirconium was discussed with relation to liquid coolants and carbon dioxide. Zirconium showed excellent resistance to pure sodium and sodium potassium alloy and may be used safely at temperatures over 800°C. The U.S. Sodium Reactor Experiment uses sodium as coolant with graphite as the moderator, zirconium is proposed as the canning material for the graphite to operate at temperatures between 515 and 650°C.

Excessive oxygen concentration in liquid metal has been shown to have deleterious effects on the corrosion resistance properties of zirconium. At a concentration of 700 p.p.m. the attack is significant whilst at 40 p.p.m. no measurable reaction takes place. In a carbon dioxide-cooled reactor measurements indicate that zirconium will exhibit good corrosive properties at 400°C. The oxidation resistance however falls off appreciably at temperatures in excess of this and at 550°C the oxidation rate is excessive.

In the accompanying comparison of possible canning materials for gas-cooled reactors no account was taken of the ease of consolidation. Zirconium is much more easily converted to a billet for fabrication than beryllium, molybdenum or niobium and the fabrication of zirconium would appear to be more suitably classed under 'good' than 'reasonable'.

It should be noted that welds of zirconium metal have been found to behave in exactly the same manner as the parent metal if prepared in an argon arc. The effect of irradiation on the properties of zirconium compared to other metals is shown in Figs. 5 and 6.

The price quoted by the Carborundum Metals Co. Inc. for reactor grade sponge varies from 22 dollars per lb. for small lots to 14 dollars for 3,000 lb. or over. Reactor ingots are offered at 23.07 dollars per lb. and the same price is charged for Zircalloy ingots.

Ductile zirconium has applications for non-nuclear uses, e.g. in surgery and the electronic and electrical fields but the quantities of metal required can never be very great. The main hopes for expansion in non-nuclear uses for ductile zirconium are based on its excellent corrosion resistance and satisfactory mechanical properties. As the presence of hafnium in the amounts usually found in the minerals does not affect the corrosion resistance it is not necessary to employ the expensive separation process nor to modify the zirconium by alloying but it is still essential to avoid contamination by impurities such as carbon which very considerably impairs the corrosion resistant properties of the metal.

The resistance of zirconium to hydrochloric acid is known to be very good, particularly if the metal is low in carbon and this has suggested the possibility of replacing tantalum for equipment handling concentrated hydrochloric acid, particularly as the volume/weight ratio of zirconium (density 6.5) is so much more favourable than that of tantalum (density 16.6). There can be little doubt that the price of zirconium will fall whilst little change can be expected in the cost of tantalum. The restrictions imposed by the limited size of tantalum billets

Zirconium: 3ème Partie—Propriétés et Emplois

Le prix actuel élevé du zirconium a considérablement limité ses applications au programme d'énergie atomique, pour laquelle sa coupe réduite en neutrons et ses bonnes propriétés de corrosion sont de valeur en tant que matériau de construction et de couverture. Un résumé des propriétés significatives du zirconium est fourni, y compris les propriétés principales physiques et les propriétés mécaniques du zirconium travaillé à froid, recuit et étiré solide, fabriqué selon les procédés Kroll et à l'iodure. On y discute aussi l'effet des impuretés sur la résistance à la corrosion, et les effets des divers agents corrosifs y sont énumérés. Le taux de corrosion par l'eau pure peut être exprimé au moyen de l'équation empirique $N=kt^n$. La valeur initiale de n est environ un demi, mais après un certain temps elle augmente à un, la période de passage étant dénotée comme la décomposition. La contamination par l'azote et le carbone sont les problèmes les plus sérieux de la production de bonnes propriétés de corrosion, bien que l'addition d'étain le compense en partie. La formule optima pour la composition de alliage de Zircalloy-2 y est donnée aussi. L'article se termine par un résumé de la valeur du zirconium dans les réacteurs, et il conclut que le zirconium est compatible à l'uranium jusqu'à 600°C, au sodium à des températures allant jusqu'à 800°C et au gaz carbonique jusq'à 400°C.

Zirkonium: Teil III—Eigenschaften und Verwendung

Der gegenwärtige hohe Preis von Zirkonium hat seine Anwendung im Kernkraftprogramm stark eingeschränkt, obwohl sein geringer Neutron-Querschnitt und seine günstigen Eigenschaften inbezug auf Rostgefahr es sowohl als Baustoff, wie auch als Schutzbelag wertvoll machen. Est wird eine Zusammenstellung der wichtigsten Eigenschaften des Zirkons gebracht und zwar der hauptsächlichsten physikalischen Eigenschaften, dann der mechanischen Eigenschaften für kalt verarbeitetes, ausgeglühtes und hart gezogenes Zirkon nach dem Kroll'schen und Iodid-Verfahren. Die Wirkung von Verunreinigungen in Bezug auf den Widerstand gegen Rosten wird diskutiert, und es wird eine Liste der verschiedenen Korrosion hervorrufenden Stoffe gebracht. Die Korrosionswirkung reinen Wassers kann durch die empirische Gleichung $\triangle N=kt^n$ ausgedrückt werden. Der Anfangswert von n ist ungefähr einhalb, wächst aber nach einer gewissen Zeit auf eins an, wobei der Zeitpunkt, an dem der Wechsel stattfindet, als "Bruchpunkt" bezeichnet wird. Stickstoff and Kohlenstoff sind die Verunreinigungen, die die schwierigsten Probleme mit sich bringen, wenn gute, Korrosion hindernde Eigenschaften verlangt werden, obwohl schon die Beifügung von Zinn eine teilweise Gegenwirkung ausüben kann. Es wird dann die Formel für die beste Zusammensetzung einer Zirkonlegierung "Zircalloy 2" gegeben. Der Artikel schliesst mit einer Uebersicht über den Wert von Zirkon in Reaktoren, wobei der Schluss gezogen wird, dass Zirkon mit Uran bei Temperaturen bis zu 600°C, mit Natrium bei über 800°C und mit Kohlensäure bis 400°C zusammen verwendbar ist.

Zirconio: Parte III—Propiedades y Usos

El alto precio actual del zirconio ha limitado en gran parte sus aplicaciones en el programa de energía nuclear en el cual su baja sección transversal neutrónica y buenas propiedades corrosivas resultan valiosas como material construccional y de revestimiento. Se ofrece un resumen de las propiedades características del zirconio, incluyendo sus principales cualidades físicas y las propiedades mecánicas del zirconio trabajado en frío, recocido y estirado sólido con el procedimiento Kroll y del yoduro. Se discute también el efecto de las impurezas en su resistencia a la corrosión y se citan los efectos de varios agentes corrosivos. La razón de corrosión por el agua pura puede ser expresada por la ecuación empírica de $\triangle N=kt^n$. El valor inicial de n es aproximadamente de un medio pero tras un período aumenta a uno denotándose el tiempo de pase como la descomposición. La contaminación por nitrógeno y carbono son los problemas más serios en la producción de buenas propiedades corrosivas, aunque la adición de estaño lo neutraliza en parte. Se ofrece también la mejor fórmula para la composición de la aleación de "Zircalloy 2". El artículo termina con un resumen del valor del zirconio en los reactores, y llega a la conclusión que el zirconio es compatible con el uranio hasta 600°C, con el sodio hasta temperaturas de más de 800°C y con el dióxido de carbono hasta 400°C.

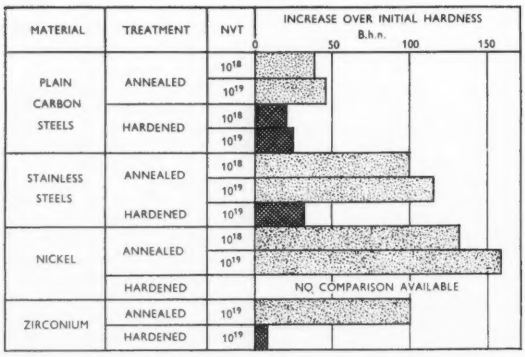


Fig. 5. Effect of irradiation on hardness of some metals.

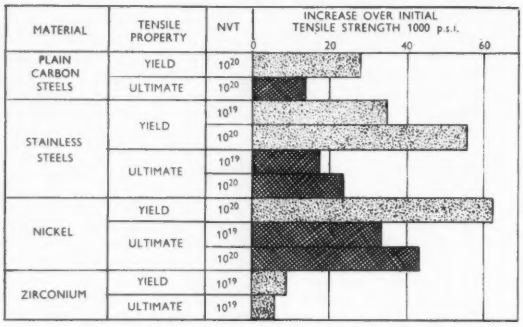


Fig. 6. Effect of irradiation on tensile strength.

due to the powder metallurgical method of consolidation do not apply to zirconium and 3,000-lb. ingots are contemplated. There is the further advantage that zirconium can be cast to shape, a method of working that cannot be applied to tantalum with a melting point approaching twice that of zirconium.

The only large-scale use for zirconium at its present price however, is as a nuclear material and a zirconium industry can only be established in conjunction with an atomic energy programme.

In a recent survey published in 1952[6] the non-nuclear demand for ductile zirconium for varying price levels, was estimated as follows:

Ingot price: $ per lb.	*Non-nuclear demand: tons*
25.00	10
8.00	120
2.50	1,500

The present price of commercial zirconium sponge quoted by the Carborundum Metals Co. Inc. varies from 10 dollars per lb. for small lots to 7.50 dollars per lb. for quantities of 3,000 lb. or over. The ingot price for commercial metal is 14.40 dollars per lb. and on this basis the usage by the above estimate should be at about 50 tons. The reason that the non-nuclear usage of ductile zirconium does not approach the estimated value is probably the time lag caused to a great extent by a concentration on atomic energy applications.

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Periscopic T.V. Equipment for Furnace Observation

A NEW type of periscopic television equipment designed to overcome the problems of furnace observation has been undergoing extensive tests at Barking "C" power station. The unit is so designed to enable the whole of the burner wall and all burners to be observed simultaneously from a single position, and televized to any part of the station.

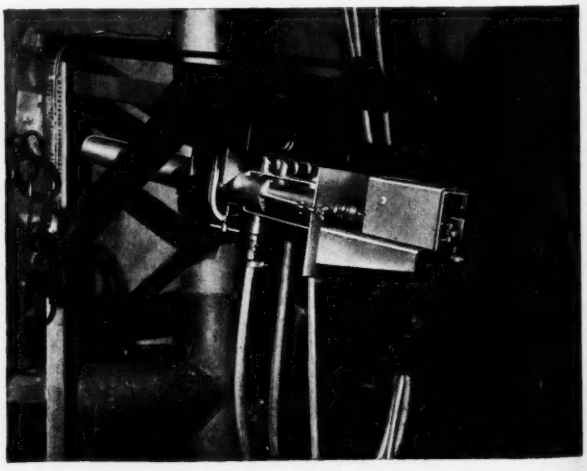
The furnace wall aperture required is only 4 in. in diameter, and the unit has been developed to suit pressurized furnace operation, so that it can be inserted or withdrawn with ease and safety against furnace pressures of up to 20 in. water gauge. It can be left in position continuously, if desired, and has many other interesting features, including automatic or semi-automatic "turn-down" operation which makes the camera tube quiescent until a picture is required.

The lens system incorporates "entrance pupils" of the minimum possible diameter which are recessed so that the apertures can be kept free from fly ash. The over-all design of the unit is such that it produces a comprehensive view of the interior, which, in some furnaces, could only otherwise be obtained by the use of at least two cameras operating from different viewpoints.

The periscope, which is completely water-cooled, with incorporated air-blast to keep fly ash from settling on the lens windows, is mounted, together with its associated television camera, on a carriage which can be advanced into the furnace or retracted by means of a Martonair remote-controlled air cylinder.

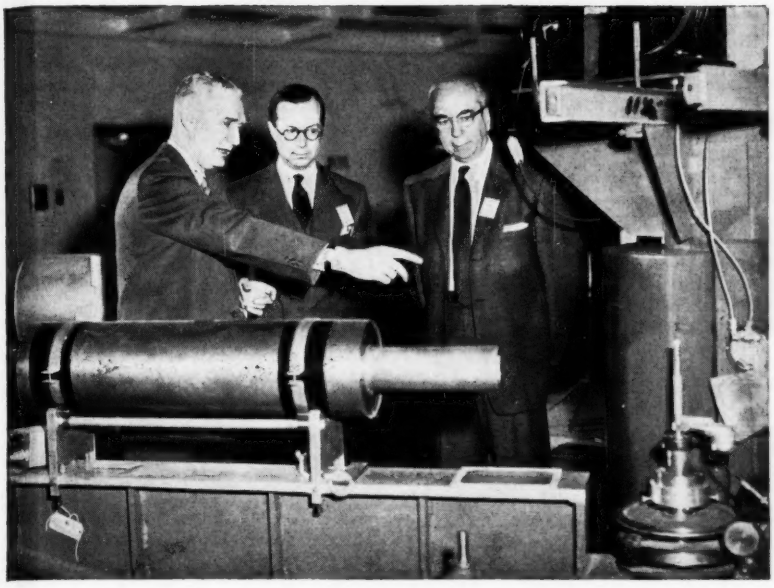
Whilst the main objective lens is of conventional design, it can be located some distance away from the furnace end of the periscope. The actual observation is carried out by the use of twin entrance apertures with lenses and prisms so arranged that the two fields of view are combined in panoramic form with a dividing line at the centre of the picture. A field of 90° in one plane and 45° in the other plane can quite easily be resolved, thus permitting the observation of a complete burner wall from a position above the burners.

The periscopic T.V. unit has been developed by Babcock and Wilcox Ltd. in conjunction with the British Iron and Steel Research Association, Marconi's Wireless Telegraph Co. Ltd. and the Foster Instrument Co. Ltd. The periscopic viewer is also available as a portable unit without the T.V. equipment. The camera is noteworthy for its very small dimensions; it employs a miniature Vidicon pick-up tube which is only 1 in. in diameter.



Periscopic television equipment for furnace observation at Barking "C" power station.

World News



Sir Edwin Plowden (centre), chairman of the U.K.A.E.A. with Dr. Walter H. Zinn (left) director of the Argonne National Laboratory, and Mr. Lewis L. Strauss (right), chairman of the U.S.A.E.C., at the Argonne Laboratory which he visited during his recent tour of atomic energy establishments in the United States.

INTERNATIONAL

Monsieur Spaak left for Paris on June 12 to discuss the drafting of treaties on the proposed European atomic energy pool with Monsieur Pineau, the French foreign minister. The intergovernmental conference meeting in Brussels on June 26 also came under discussion.

A symposium on high energy physics was held in Geneva during the week June 11-23 at which some 300 scientists, including 60 from the Soviet Union, were present. Sir John Cockcroft was among the British delegation. The symposium had been called under the auspices of CERN, the European Organization for Nuclear Research, and it was confined to fundamental physics questions with particular relation to the high voltage generating equipment under construction at Meyrin, just outside Geneva, with a 25 GeV output. Delegates to the conference were able to visit the site and to examine the proton-synchrotron.

The World Health Organization completed its 9th conference on May 25. Delegates from 76 countries had attended and they agreed that a programme should be set up to study health problems associated with atomic energy projects, including the disposal of radioactive waste. Training personnel has also come under review. The W.H.O. plans to spend nearly £4 million in the coming year and if the Eastern bloc resumes full participation an additional £½ million will be forthcoming.

Vienna will probably be chosen as the permanent headquarters for the international agency discussed by the 12-nation conference in April. The U.K., U.S.A., U.S.S.R. and France have all informed the foreign minister, Dr. Figel, that they would support the Austrian proposal. Other nations also are reported as being in favour of Vienna as the central location.

UNITED KINGDOM

Thermo-nuclear energy. A conference on the control of thermo-nuclear energy, which took place at Harwell on June 4, was attended by many representatives of universities and industry. No reports, however, on the conference have been given and the discussions that took place are liable to remain classified for some time.

A pact between Britain and America for the exchange of information on atomic energy was signed on June 14. This is one of the most comprehensive exchange agreements that has been made and although weapon design is not included full information is to be exchanged on such military topics as naval ship propulsion. It is believed also that Britain will have access to American developments of nuclear powered aircraft.

Increase in power programme. Mr. Aubrey Jones, in reply to questions in the House of Commons, has stated that it will be possible in due course to accelerate the original power programme in this country. At present, however, reappraisal must await the designs to be submitted by industry to the C.E.A. and for the C.E.A.'s consideration. Tentative figures suggest that the 12 stations originally scheduled for completion by 1965 might be increased to 20, all with very large outputs.

Loughborough College of Technology has announced that a post-graduate course of one year's duration in industrial engineering will be inaugurated next September. The course will include special lectures on nuclear energy. Particulars can be obtained from the Head of the Department of Industrial Engineering, Loughborough College of Technology, Loughborough, Leicestershire.

AUSTRALIA

A uranium nugget weighing just under a ton and worth nearly A£7,000 has been found in a mine on the South Alligator River. This is believed to be the biggest single find of uranium ever recorded.

Ten or eleven tons of heavy water are to be purchased from the U.S.A.E.C. as part of the Australian programme for nuclear research. In answer to questions in Parliament, Mr. Beale assured questioners that this was a straight commercial undertaking and did not represent any tighter tie-up with the U.S.A. Later, on June 19 he announced that an agreement on information exchange had been concluded.

CANADA

Uranium purchase. The United Kingdom is negotiating with the Eldorado Mining and Refining Ltd. for the purchase of a substantial quantity of uranium in the next five years. Canadian production of uranium is already considerably in excess of her internal demands and it has been estimated by the president of Atomic Energy of Canada Ltd. that it will approach a value of $250 million a year by 1959. If this figure were achieved Canada would be the world's largest producer of uranium.

Metal production. Discussions are in hand over the setting up of a metal refining plant for the production of uranium metal. In a statement recently, the Trade Minister, Mr. Howe, announced that Canada may be producing metal in about one year, but that sales of this would be a function of refining costs.

Rapid progress is being made on the 20-MW nuclear power station at the Des Joachims power plant of Ottawa Hydro-Electric Power Commission. The plant is being built jointly by Canadian General Electric and by Ottawa Hydro-Electric Energy of Canada. The invested capital is estimated at between 13 and 15 million dollars.

Large power stations. The Atomic Energy of Canada Ltd. and a number of electricity companies are engaged on preliminary designs of large scale nuclear power stations to generate 100-200 MW electricity. Consideration is also being given to nuclear power plants to provide electricity and low pressure steam for the pulp and paper industry.

New refining process. At the 39th conference of the Chemical Institute of Canada, Professor A. B. Van Cleave described the new process for the treatment of uranium ore in which the ore is crushed to dust and is then subjected to a floating and settling process. This is an extension of techniques already common in the mining industry but is the first time that the idea has been applied to uranium extraction. It is hoped to make the exploitation of ore containing 0.05% uranium oxide an economically practical proposition.

FRANCE

Saclay mishap. Breakdown of a fuel element casing has caused a temporary shutdown of the pile at Saclay. As a result of the accident a small amount of activity was released into the atmosphere. The damage, however, was not serious and contamination has been very small. Repairs can be effected quickly and hold-up was expected to be only temporary.

A nuclear powered submarine is to be built in France. The engineer in charge of operations will be Monsieur Roger Biard. Reports earlier last month that the Commissariat and Shell Francaise were co-operating to finance the construction of a nuclear powered tanker have been denied. As in the U.K. it is likely that developments will be confined to naval vessels for some years.

GERMANY

A rapid expansion of the atomic energy programme has been outlined by Herr Strauss, the Western German minister for atomic affairs. Herr Strauss recently completed a tour of U.S. installations and is planning a similar tour of Britain to arrange a bilateral agreement between the two countries for the purchase of fuel. Plans have been laid for research reactors to be built at Munich, Hamburg and Frankfurt, two to be of the swimming pool type and one a hot water boiling reactor. The first has been ordered from American Machine and Foundry Company, price being $450,000, and the second will probably be supplied by Babcock and Wilcox, N.J., for the same figure. North American Aviation are expected to receive the B.W.R. contract.

Two reactors are to be erected in Westphalia, the first of which, the swimming pool type, is already ordered from the A.E.I.-John Thompson Nuclear Energy Co. Ltd. The second will be a materials testing reactor and may be purchased in the U.K. It is probable that this reactor will be a heavy water moderated type similar to Dido or Pluto and will be supplied by Head, Wrightson and Co. Ltd.

At Karlsruhe, under the direction of Professor Karl Wirtz, an experimental reactor is to be constructed on the lines of Bepo by German technicians. The project is financed partly by the Federal and Württemburg Governments and partly by a consortium of industrial companies. The total investment is estimated at £3½ million.

A small prototype power reactor is under consideration by the Rhenanian-Westphalia Electricity Board. It is reported that discussions are already in hand between the board and Babcock and Wilcox of America.

INDIA

Heavy water delivery. The first 7 tons of heavy water, part of the 21 tons that India has agreed to buy from the United States, were shipped from America on May 19 and unloaded in Bombay on June 8. Canada is building a second NRX reactor under the Colombo Plan at Trombay which is expected to commence operation in 1958.

Thorium plant. Work on the expansion of the thorium extraction plant at Trombay to exploit the huge monazite deposits in Travancore was completed early this year. Original enlargement of the plant was completed in August, 1955, and a 30% increase in production was found possible two months later. India expects not only to be able to fulfil her own nuclear energy requirements from the plant but also presumably to make considerable quantities available for export. Since 1946, up to which time the bulk of thorium ore treated in the world had come from India, export restrictions have forced other countries to look elsewhere for their raw materials.

The Prime Minister, Mr. Pandit Nehru, in a speech in the Rajya Sabha on May 25, spoke on the second five year plan and laid particular emphasis on the importance of accelerating the use of atomic energy. The plan makes provision for considerable expansion in industry and agriculture and only recently has emphasis been laid upon the exploitation of atomic energy.

JAPAN

Nuclear power station from Britain. The chairman of Japan's Atomic Energy Commission has announced that Britain would sell Japan a nuclear power station with a generating capacity of approximately 100 MW. A tentative cost for the station has been quoted at £15 million. This announcement was made approximately one week after Sir Christopher Hinton had sailed from Japan after completing a short tour of lectures.

NEW ZEALAND

Uranium deposits have been reported in the lower Buller valley in the South Island, in which concentration is reputed to be satisfactory. The extent of the deposits at present is not known and it will be recalled that earlier reports from New Zealand which caused a minor uranium rush there were followed by disappointment.

U.S. agreement. The acting Prime Minister stated on June 14 that the Government had completed an agreement with the U.S. for the exchange of information on the peaceful uses of atomic energy and for permission to lease enriched uranium for reactor research use. In the agreement American companies will also be in a position to supply equipment.

PAKISTAN

Reactor construction approved. The Atomic Energy Council of Pakistan announced in Karachi on June 4 that the construction of two reactors has been approved in principle. The first of these is to be a medium power research reactor located in Western Pakistan and the second a nuclear power station in the east. The research reactor is hoped to be in operation by 1959.

Four medical centres at Karachi, Multan, Lahore and Dacca, for the diagnostic and therapeutical use of radio-isotopes, are to be opened in the near future and at a later stage a research centre for the application of radio-isotopes to agriculture is to be established.

PORTUGUESE EAST AFRICA

A concession to prospect for minerals such as berylium, tantalum, zirkelite, diamonds, etc., has been granted to The Central Mining and Investment Corporation Ltd., of South Africa. The concession, however, does not include radioactive minerals.

SOUTH AFRICA

A Nuclear power station? Recommendations by a special commission on atomic energy are being considered by the South African cabinet. The secretary of the S.A.A.E.B., Mr. J. A. Reid, is reported as stating that work on a nuclear power station might begin in the very near future, near Capetown, if the Government agrees with the proposals. Conventional power stations in Capetown area use approximately 2,000 tons of coal a week which has been hauled over 1,000 miles, and in spite of the very low cost of coal in South Africa it is thought that a nuclear power station might be competitive in cost.

Au and U. A mine capable of producing gold and uranium simultaneously has been opened at Orkney near Klerksdorp. The mine is operated by the Anglo-American Corporation of South Africa and is likely to become the centre of a considerable industry as indications are that the older mines of the Witwatersrand were meeting increasing difficulties in production.

SWITZERLAND

Agreement with U.S. Although the Swiss foreign minister had been negotiating with the U.S.A. for an agreement on the sale of raw materials and the exchange of atomic energy information, considerable difficulties were being met in dovetailing the security restrictions of the two countries.

These problems have now been overcome and an agreement for the exchange of both classified and non-secret information was signed on June 21. Provision is made in the treaty for Switzerland to buy 500 kg. of enriched uranium.

U.S.A.

The organic moderated reactor has been chosen by American and Foreign Power Co. Inc. to be constructed by Atomics International for installation in one of the Latin-American countries. The site of the reactor has not yet been determined but an output capacity of 10½ kW is envisaged. Details of the installation will have to wait on the OMRE experiments now in hand. The second reactor to be purchased by the company will be manufactured by the General Electric Company and will be a single cycle boiling-water type with a similar installed capacity.

Reactor systems. The A.E.C. is to increase the number of research reactors for power station investigations to 8 by calling for plans and tenders for a gas-cooled type, to be built at the National Testing Station in Idaho. The value of the contracts is estimated at £1½ million. Last month Babcock & Wilcox, with Union Carbide Nuclear Company as a major subcontractor, were awarded a contract for the building of a liquid metal fuelled reactor out of a total of 10 competing companies. Other types under investigation are a pressurized water, a boiling water, a sodium-graphite, an organic moderated, a homogeneous and a fast breeder reactor.

The U.S. Senate has approved a bill for the construction of a nuclear powered merchant ship at an estimated cost of £13¾ million. The "peace ship" proposed by President Eisenhower has again not received Government sanction.

Four processing plants to be financed and operated by private industry are to be put up in Colorado. Atomic Fuel Extension Corporation and Union Carbide Nuclear Company are to each start work on plants in the near future as a result of contracts awarded to the companies by the A.E.C. It is expected that both plants will use acid leaching and iron exchange processes.

General Electric is to build a boiling water reactor at the new Vallecitos Atomic Laboratory to be in operation by next year. The main purpose of the reactor will be to furnish operational data for the 180 MW plant to be built for the Commonwealth Edison Company. It will be provided with turbine generating equipment and power produced will be distributed into the local transmission network.

Babcock and Wilcox fuel element fabrication plant is now in operation at Lynchburg, Va. It is the first privately financed works of this type and works in conjunction with a laboratory for the study of reactor core components. Fabrication at present largely is confined to the flat plate type nuclear fuel elements in general use throughout the U.S., but it is expected that other types will be produced in the near future.

U.S.S.R.

Reactor powered transport continues to figure in reports on U.S.S.R. developments. In recent statements by Mr. E. V. Slavasky, director of the Central Board for the Use of Atomic Energy, he observed that a reactor powered plane would be produced in the not too distant future. Earlier, a reactor powered ice-breaker had been quoted as designed with a displacement of 16,000 tons and a s.h.p. of 44,000 which will give the ship a maximum speed of 18 knots. It is reported also that nuclear powered whaling vessels and small power stations, capable of being transported by rail, are also under development.

The five nuclear power stations with a total generating capacity of 2,000 MW to be completed by 1960 will be sited in Moscow, Leningrad, the Urals and the Sverdlov region.

Trade Notes

Vickers Ltd. has acquired a controlling interest in Canadian Vickers of Montreal, thus re-entering the Canadian market through the same company that Vickers itself founded in 1911 and operated until 1927. Vickers Ltd. has also formed Vickers Australian Pty. Ltd., in Melbourne to take over their Australian investments.

Henry Wiggin and Co. Ltd. have purchased the specialized high nickel alloy fabricating plant at Hereford which they designed and erected for the Ministry of Supply, and which they have been operating since 1954.

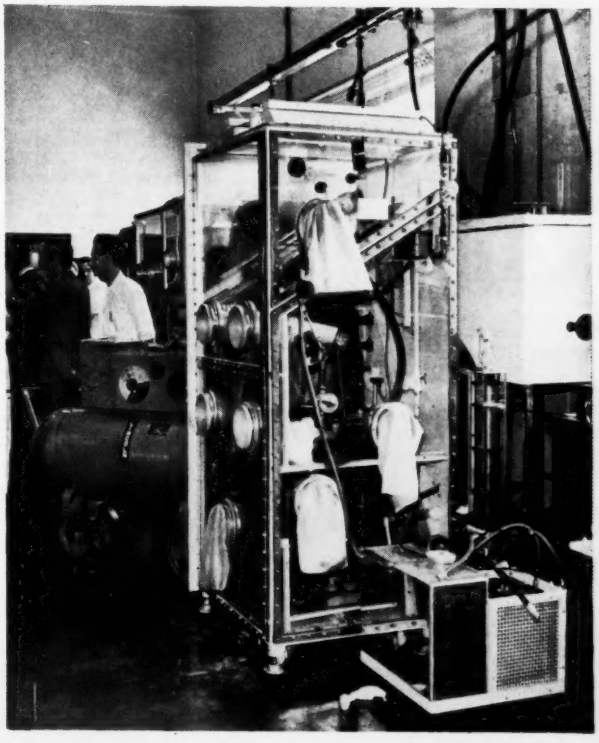
The Air Survey Co. Ltd., 24 Bruton Street, London, W.1, is now to be known as Fairey Air Surveys Ltd., thereby adopting the name of the parent company of which it has been an integral part for 27 years.

The department of E.M.I. Institutes which provides full-time day courses in radio and electronic engineering is now to be known as the E.M.I. College of Electronics. Its headquarters are at 10 Pembridge Square, London, W.2.

Address of the head office and showrooms of the Compoflex Co. Ltd., is now 23-25 Northumberland Avenue, London, W.C.2 (Telephone: Trafalgar 7800). The new showrooms will enable samples of all the company's sizes and types of flexible tubes and hoses to be displayed.

Correction: In the article on "Clad Steel Plates" in the June issue the name of the metal deposition process was wrongly given as Lincold; this should, of course, have been Lincoln, the Spreadarc apparatus being made by Lincoln Electric Co. Ltd., Welwyn Garden City, Herts.

Two important civil engineering companies — Balfour, Beatty and Co. Ltd., and John Laing and Son Ltd. have been appointed civil engineering contractors to the A.E.I. — John Thompson Nuclear Energy Co. Ltd. They will be associated in the preparation of a tender for the C.E.A. nuclear power stations. Balfour, Beatty have long been active in the building of power projects, particularly in Asia. Laing's have extensive organizations in Canada and Africa.



Arc melting unit by Lincoln, fitted to a Perspex cabinet for totally enclosed high temperature plutonium work. The arc is manually controlled through the gloves.

Canadian Westinghouse Co. Ltd. have announced the formation of an atomic energy division. It will operate as part of the company's project development group which also includes an electronics division.

Baird and Tatlock (London) Ltd. announce that they have been appointed suppliers to the U.K. Atomic Energy Authority.

Instrument repair, reconditioning and recalibration service is being offered by Donvin Instruments Ltd., Electrin Works, Winchester Street, London, W.3, a member of the Pullin group. A variety of work ranging from miniature industrial switchboard meters to precision laboratory instruments is already being carried out on a 14 to 21 day delivery. A special "crash" scheme for emergency repair work has been instituted whereby the repair of most types of switchboards, and portable electrical instruments and test sets can be undertaken within 48 hours of receipt.

A coloured chart which illustrates the construction and functions of the synchro-cyclotron is available free of charge to technical colleges and scientific training establishments from the Scientific Equipment Department of Philips Electrical Ltd., Century House, Shaftesbury Avenue, London, W.C.2. The chart measures 47 in. x 31 in. As supplies are limited, issue can be made on the basis of only one per applicant.

State Labs Inc., 649 Broadway, New York, 12, have been appointed exclusive agents in the U.S.A. and Canada for the L.M. Ericsson Corporation of Sweden.

London Metal Warehouses Ltd., Summer Road, Thames Ditton, Surrey, suppliers of stainless steel and non-ferrous metals, have increased the efficiency of their delivery service by the addition of three 5-ton Morris lorries to their fleet.

New research laboratories of the Solartron Electronic Group Ltd., at Goodwyns Place, Dorking, Surrey, were officially opened on May 24 by Sir Walter Puckey.

The Harland Engineering Co. Ltd., Alloa, have transferred the manufacture of their small and medium standard pumps to a new plant at Timperley, Cheshire. Mr. R. W. Weekes, managing director, states that the move has been planned so as to enable the Alloa works to concentrate on the production of heavy equipment. Various extensions are already in progress. When complete they will facilitate the manufacture by the company of the largest sizes of water turbines and the special plant needed for thermal and nuclear power generation.

Personal

BIRTHDAY HONOURS LIST

Viscount

The Rt. Hon. Frederick Alexander, Baron Cherwell, lately Professor of Experimental Philosophy, Oxford.

Barons

Lt.-Gen. Sir Ronald Morce Weeks, formerly chairman, Vickers Ltd.; chairman, National Advisory Council for Education in Industry and Commerce; president, British Scientific Instrument Research Association.

Knights

Mr. Horace William Clarke, chairman, Aluminium Industry Council. **Mr. George Herbert Dowty,** chairman, Dowty Group and subsidiaries. **Mr. Horace S. Gibson,** managing director, Iraq Petroleum Co., and associated companies.

C.M.G.

Mr. D. H. Black, Chief Scientific Officer, Ministry of Supply.

C.B.E.

Mr. J. R. V. Dolphin, chief engineer, Atomic Weapons Research Establishment, U.K.A.E.A. **Mr. J. Sullivan**, part-time member, South of Scotland Electricity Board, chairman, Electricity Consultative Council for the south of Scotland district. **Dr. C. Sykes**, managing director, Thomas Firth and John Brown Ltd.

O.B.E.

Mr. R. A. Browning, director of contracts, U.K.A.E.A. **Mr. A. H. Layhe,** manager (purchasing), British Insulated Callenders Cables Ltd. **Mr. S. Partington,** internal head of works, Salford Electrical Instruments Ltd., Lancs.

M.B.E.

Mr. G. L. Cardwell, chief die designer, drop forge dept., English Steel Forge and Engineering Corp. Ltd. **Mr. J. Crowther,** chief metallurgist, James Booth and Co. Ltd., Birmingham. **Mr. K. E. B. Jay,** principal scientific officer, scientific administration division, A.E.R.E., Harwell. **Mr. D. R. E. O'Neill,** technical sales manager, London Aluminium Co. Ltd., Birmingham. **Mr. G. S. Palmer,** manager, titanium melting plant, William Jessop and Sons Ltd.

Air Chief Marshal Sir Ralph Cochrane has joined Rolls-Royce Ltd., in charge of administration of the company's nuclear energy projects.

Mr. W. M. York, formerly an executive director, has been appointed commercial director of E. K. Cole Ltd.

Viscount Knollys, G.C.M.G., M.B.E., D.F.C., succeeds **Sir Ronald M. Weeks,** K.C.B., C.B.E., D.S.O., M.C., T.D., as chairman of Vickers Ltd. Sir Ronald, created a Baron in the Birthday Honours, will continue as a director of the company.

Mr. H. V. Schofield has resigned from his position as sales director of the Chloride Electrical Storage Co. Ltd. He retains his seat on the board.

Dr. L. W. Nordheim, professor of physics at Duke University and one of the first scientists to take part in nuclear research at Oak Ridge, has joined the General Atomic Division of General Dynamics Corporation.

Dr. Lloyd P. Smith, chairman of the Department of Physics at Cornell University, has been appointed president of the research and advanced development division of Avco Manufacturing Corporation.

Mr. J. W. Kendall, previously with the U.K.A.E.A. (Industrial Group), has joined John Thompson Water Tube Boilers Ltd. in a senior advisory capacity. He is a leading authority on the design and construction of gas-cooled graphite-moderated reactors.

Mr. Norman Baker, chief estimator, is to join the board of Taylor Woodrow Construction Ltd.

Mr. J. S. Rivaz, A.R.Ae.S., has been appointed technical sales manager to Smiths Aircraft Instruments Ltd., in succession to **Mr. A. I. O. Davies.** Mr. Rivaz was formerly technical services manager of Kelvin and Hughes (Aviation) Ltd., one of the Smiths Group of aviation companies. **Mr. Douglas G. Johnson,** formerly deputy technical sales manager, has been appointed contracts manager. **Mr. Brain Cape**, A.I.E.E., succeeds Mr. Rivaz as technical services manager to Kelvin and Hughes (Aviation) Ltd.

Mr. John G. Thom, A.M.I.W., has been appointed sales manager for Northern Ireland by British Oxygen Gases Ltd.

Dr. Robert B. Duffield, associate professor of chemistry and physics at the University of Illinois, will head the chemistry programme of the general atomic division laboratory of General Dynamics Corporation.

Sir John Cockcroft, K.C.B., C.B.E., F.R.S., has been awarded the Kelvin Gold Medal for 1956. Administered by the Institution of Civil Engineers the Medal is awarded every three years "as a mark of distinction in engineering work of the kinds with which Lord Kelvin was especially identified," and is internationally regarded among engineers as the highest distinction attainable.

Mr. Ian T. Morrow has been elected president of the Institute of Cost and Works Accountants. He is joint managing director of the Brush Group Ltd.

Mr. John R. Rylands, M.Sc., M.I.Mech.E., M.I.E.E., F.Inst.F., is to succeed **Mr. R. H. Gummer** as president of the Institute of Fuel. He will take up the position in October of this year. Mr. Rylands is at present chief engineer and a director of E. Green and Son Ltd.

Mr. G. N. Hodson (Hathernware Ltd.) a past vice-chairman, was elected chairman of the British Chemical Plant Manufacturers Association at the A.G.M. on May 8. The following were elected to the Council: **Mr. J. Bishop** (Nordac Ltd.), **Mr. J. C. Haithwaite** (John Thompson (Dudley) Ltd.), **Mr. I. M. O. Hutchison** (Henry Balfour and Co. Ltd.), **Mr. B. H. Turpin** (Q.V.F. Ltd.), and **Mr. M. Wyndham** (Bennett, Sons and Shears Ltd.).

At its meeting immediately following the A.G.M., the Council made the following elections: **Mr. H. W. Fender** (Prodorite Ltd.), **Mr. I. M. O. Hutchison** (Henry Balfour and Co. Ltd.), and **Mr. R. W. Rutherford** (Power-Gas Corporation Ltd.) as vice-chairman, and **Mr. P. W. Seligman** (A.P.V. Co. Ltd.) as honorary treasurer.

Mr. W. B. Homer and **Mr. T. R. Davies**, of Southern Instruments Ltd., Camberley, Surrey, have recently completed a successful tour of Switzerland, demonstrating their new cathode-ray polarograph, in conjunction with their agents, Sorensen-Ardag of Zurich.

OBITUARY

It is with deep regret that we have to announce the death of **Mr. T. L. Horabin,** chairman of K.D.G. Instruments Ltd., Croydon. **Mr. R. B. Ogden**, F.C.A., has been appointed chairman.

Lord Knollys.

Mr. G. H. Dowty.

Dr. C. Sykes.

Mr. W. M. York.

Mr. I. T. Morrow.

Technical Papers and Publications

WORLD POWER CONFERENCE
Vienna, June 17-23, 1956

The Technical Problems of Designing and Operating Reactors for Producing Electrical Power and the Problems of Making them Economic *by H. H. Gott, M.A., A.M.I.Mech.E. (Industrial Group, U.K.A.E.A.).*

The paper reviews the various types of reactor which are potentially available for power production. It is emphasized that this is already a large-scale industrial and economic problem, and types of plant which do not have the backing of extensive allied engineering experience are at a disadvantage. In a fully developed power system involving a large number of units the writer wishes to see the parallel operation of gas-cooled thermal reactors and sodium-cooled fast reactors. The gas-cooled reactor produces electricity competitively without need for enriched uranium fuel or any other isotope separation plant, moreover it is inherently safe, perhaps the only reactor whose safety can be relied on under any foreseeable circumstances. The high concentration of fissile material in the fast reactor implies a need for a very high heat release, and this may be difficult to achieve for a core with a very high gain factor, a compromise must be expected. Mention of the operation of reactors is made and the possibility of carrying out maintenance work on them.

Considerations Involved in a First Nuclear-Electric Power Reactor in New England *by R. Leigh Fitzgerald (Assistant to the President, New England Electric System).*

Cost of fuel in New England is high, relative to the low United States average. This accentuates the interest of this area in a potentially cheaper energy source. Realization, at an abnormally accelerated rate of development, of economical nuclear power appears almost inevitable in the not-too-distant future. To be ready at that time, New England utilities need to start gaining experience now.

The best choice of reactor type for reliability, reasonable efficiency and adaptability to future developments at this time appears to be pressurized light-water-cooled and moderated design which has already proven its technical feasibility in the military propulsion reactor programme in the submarine "Nautilus."

Economics of Nuclear Power *by U. M. Staebler (Chief, Civilian Power Reactors Branch, Division of Reactor Developments, United States A.E.C.).*

Unfortunately, very little factual information is available on the economics of nuclear power. Economics studies based on extensive experimentation and design work have shown conditions under which nuclear power costs of seven mills per kilowatt-hour or less might be achieved in the United States from plants with 100,000 kilowatts or more generating capability.

Achieving low cost nuclear power depends upon solving many technical factors affecting the cost of power production. The rate of success in solving these problems will be the principal factor in determining the rate at which nuclear power production becomes an important part of world power production.

Atomic Energy Progress in Sweden, 1945-1955 *by Harry Brynielsson (Managing Director of the Swedish Atomic Energy Company).*

Since 1953 the Atomic Energy Company has had a uranium extraction plant running in Kvarntorp, using as raw material alum shale with a uranium content of about 200 grams per metric ton. The concentrate is purified in a chemical plant in Stockholm where also the uranium metal is fabricated.

In July 1954, the A.E.C. started the first Swedish experimental reactor R 1 in an underground laboratory in Stockholm. This reactor provides information about the running of reactors and the arrangements for regulation, control and measurement, protection against radiation, etc.

As the next step there are plans to build a development reactor with the highest possible neutron flux and with facilities for carrying out experiments at high temperatures. For this reactor and future experimental work in the reactor field, the company has acquired an area of 300 acres at Studsvik, about 80 kilometres south of Stockholm.

Plans for the first atomic power stations are being worked out in collaboration between power producers, the Atomic Energy Company and the manufacturing industry, and it is hoped that the first prototype will be in operation within seven years at the latest.

Disposal of Atomic Wastes in the Atomic Energy Industry *by A. E. Gorman and G. E. McCallum (Sanitary Engineer U.S. Atomic Energy Commission and Sanitary Engineer Director U.S. Public Health Service).*

While the power industry is making extensive plans for world wide use of atomic energy, it must also evaluate the environmental problems associated with the release of radioactive and toxic wastes from this new industry. Important among these considerations are careful selection of sites for nuclear reactors and chemical plants for processing fuel elements. Experience in the United States in resolving these problems has called for co-operation at high technical levels by many professions. Furthermore, it has indicated that site selection and waste disposal are important considerations in relation to planning of plant facilities and obtaining approval of public health and safety officials in locating new plants especially in the more populated areas.

Atomic Fuels *by F. H. Spedding (Director, Institute for Atomic Research and Ames Laboratory of the A.E.C. Iowa State College).*

A number of basic factors that determine the type of fuel elements or assemblies which would be used in an economical power reactor are discussed. Particular emphasis is placed on those factors which markedly influence the reactor design, the desirable fuel cycle to be used, and the net cost of producing power from such reactors.

The Disposal of Waste Waters and Gases in a Nuclear Power Programme *by H. J. Dunster, A.R.C.S., B.Sc., D. R. R. Fair, O.B.E., B.Sc., A.Inst.P., A.K.C., and A. S. McLean, M.B., Ch.B., D.I.H. (U.K.A.E.A.).*

The principal sources of radioactive wastes are reviewed and their relative importance is indicated. Both reactor and chemical processing plants are considered. Typical methods of disposing of these wastes are outlined and, as an example, a brief indication is given of the practices adopted in the United Kingdom. It is concluded that the technical problems of waste disposal are already yielding to investigation and that there is no suggestion that the realization of nuclear power will be delayed on this account.

The Methods of Using Fuels in a Nuclear Power Programme (including some notes on Reactor Types and Uses) *by J. V. Dunworth, C.B.E., M.A., Ph.D., F.Inst.P. (Head of Reactor Physics Division, A.E.R.E., Harwell).*

Future high output reactor developments are likely to be associated with three distinct types of system. First, there is a thermal or near-thermal heterogeneous reactor in which a long-life fuel is used. It seems likely that chemical and metallurgical considerations as well as nuclear ones will favour the thorium-uranium-233 fuel cycle and that such a reactor will be about self-maintaining in fissile material. Initially, some of the reactors may well operate on a plutonium-uranium-238 fuel cycle.

Secondly, there is a homogeneous type of reactor which seems likely to operate only on the thorium-uranium-233 fuel cycle and the aqueous system has a long lead at present.

Finally, there is the fast or slightly moderated fast reactor which can lead to a very high gain factor using the plutonium-uranium fuel cycle, and rather lower ones using the thorium-uranium-233 cycle. In both cases some sacrifice of part or all of the gain factor is likely to ease engineering and processing problems and result in a more economic system and this could well be the method of emergence of an intermediate system. In this case, the indications are that the fuel cycle will be thorium-uranium-233 once again.

Observations on the Organization of Atomic Power Stations *by Dr.-Ing. Friedrich Munzinger.*

The paper compares the conditions in the United States, in Great Britain, and in the German Federal Republic. It comes to the conclusion that the economic prospects may differ widely between one country and another, even between one part of a country and the other. Such differences will be more visible the higher the costs are for fossile fuels and the farther away the coal mines or gas and oil resources are located from a power station. Moreover the question "Which should be preferred—atomic or fossil fuel power stations?" is not only a commercial problem, but to a high degree a sociological one as well.

Atomic Energy Metallurgical and Chemical Problems; Protective Measures *by Professor Dr. phil. Karl Lintner and Professor D. phil. Engelbert Broda (University of Wien).*

The paper reviews the metallurgical and chemical problems attendant upon the atomic energy programme, followed by a short review of protective measures. Treatment of uranium ores has recently been simplified by combining many of the operations previously used, such as directly extracting the acid solution with organic solvents without previous separation from the undissolved rock. For reactors the neutron properties of the construction materials must be examined and whilst aluminium is satisfactory from this point of view the maximum temperature is limited to 250°C. Zirconium and its alloys are promising alternatives. A number of satisfactory moderators are available of which carbon and light water are the cheapest but the recent reduction in price of heavy water has made this a more economic proposition. Beryllium is likely to remain too expensive for general use. Fission product separation raises a number of difficult problems, an interesting solution being the use of pyro-metallurgical techniques. At present solvent extraction, however, is more generally used.

Atomic Energy: Basic Principles and Design of Reactors *by Professor Dr. phil. Karl Lintner, and Dr. phil. Peter Weinzierl (University of Wien).*

The mechanism of the production of energy for reactors is discussed, followed by a brief examination of the three fuel cycles which appear to be of special interest. These are U 238-Pu 239 in a thermal reactor, Th 232-U 233 in a thermal reactor and U 238-Pu 239 in a fast reactor. A brief summary is given of the main reactors under investigation in the United Kingdom, the U.S.S.R., and the U.S.A., followed by an examination of the operating temperatures which obtain at the present time and which can be expected within the next few years.

Nuclear Generation and the Future Power System in Great Britain *by J. C. Duckworth, B.A., P. J. Squire, B.Sc., A.M.I.E.E., and V. G. Newman, B.Sc.(Eng.)., A.M.I.C.E., A.M.I.Mech.E.*

From forecasts of electricity requirements up to the year 1980 and the proportion which, it is expected, will be supplied from indigenous resources, estimates are derived of the scale of nuclear plant installation which would be needed to make good the deficiency. On this basis, it is shown that, by the end of the period under review the whole of the country's base-load would be generated by nuclear plants, although more than two-thirds of the total plant capacity would still be of conventional type. The scope for pumped storage is examined and the conclusion is reached that with progressively increasing nuclear generation the case for its adoption will be considerably enhanced. The siting of nuclear stations is discussed in relation to their technical characteristics and the economic factors relevant to the operational efficiency of the supply system as a whole.

Future Plant Requirements (Estimated September, 1955)
(Duckworth, Squire and Newman)

		1965/66	1970/71	1975/76	1980/81
(1) Estimated peak demands	MW	34,500	43,500	55,500	70,500
(2) Total plant requirements	MW s.o.	39,000	49,500	63,000	80,000
(3) Units sent out from generating stations	Mill. kWh	136,000	176,000	229,000	295,000
(4) Units from hydro stations	Mill. kWh	3,500	4,500	6,000	8,000
(5) Units required from thermal stations	Mill. kWh	132,500	171,500	223,000	287,000
(6) Units obtainable from home-produced coal	Mill. kWh	107,000	131,000	136,500	140,500
(7) Units required from nuclear fission and/or imported fossil fuel	Mill. kWh	25,500	40,500	86,500	146,500
(8) Nuclear capacity required to provide line (7)	MW s.o.	3,900	6,200	13,200	23,000
(9) Assumed annual load factor of nuclear plant	%	75.0	75.0	75.0	73.0
(10) Capacity of coal fired plant required	MW s.o.	33,600	41,600	47,700	54,400
(11) Annual load factor of coal fired plant	%	36.4	35.9	32.7	29.5
(12) Nuclear capacity as proportion of total plant requirements	%	10.0	12.5	21.0	28.8

This table covers the areas of the North of Scotland Hydro-Electric Board, South of Scotland Electricity Board, and Central Electricity Authority.

A 180 Megawatt Boiling Water Reactor Power Plant *by T. G. Leclair (Engineering Assistant to the Vice-President, Commonwealth Edison Co.).*

The principal design features of the 180,000 kW electrical output dual cycle boiling reactor are the heterogeneous, slightly enriched fuel elements, and light water heat transfer agent and moderator. The plant will be constructed on a site in the northern part of Illinois, in central U.S.A., and will be owned and operated by the Commonwealth Edison Company, a private utility supplying electricity to Chicago and Northern Illinois.

It is the largest all-nuclear plant yet proposed and will be financed entirely by private funds. The cost will be $45,000,000 or $250 per kW, plus the cost of land and overheads. The portion of the cost of the plant which is justifiable by comparative electric power cost derived from conventional coal-fired plants in the Chicago area will be borne by the Commonwealth Edison Company. The additional amount will be shared by a group of companies interested in the nuclear power field. These companies are American Gas and Electric Service Corporation, Bechtel Corporation, Central Illinois Light Company, Commonwealth Edison Company, Illinois Power Company, Kansas City Power and Light Company, Pacific Gas and Electric Company and Union Electric Company.

This type of plant has distinct possibilities as an economic future source of electric energy and, in certain high fuel cost areas of the world, is believed to be competitive now. The companies involved in this venture believe that the construction and operation of this plant will make a substantial contribution to the art of power generation and to the more efficient use of available energy sources.

Status Report on the Pressurized Water Reactor (PWR) Plant *by J. W. Simpson.*

The reactor plant consists of a single reactor heat source with four main coolant loops. Three of these loops are required for producing the 60,000 kW minimum design power. Each loop consists of a single-stage centrifugal canned-motor pump, a heat exchanger section of a steam generator, 16-in. gate-type isolation valves, and the necessary 18-in. outside diameter interconnecting piping.

High-purity light water serves as both coolant and moderator in this plant. This water is under a pressure of 2,000 p.s.i. The flow through the nuclear core is 45,000 g.p.m. for three loops. At full power the inlet water temperature to the reactor is 508°F and the outlet temperature is 524°F. The water velocity in the 18-in. pipes is approximately 30 ft./sec., with a velocity of between 10 and 20 ft./sec. in various parts of the nuclear core. The total pressure drop around the main coolant loop is 105 p.s.i., and this drop is divided roughly equally between core, steam generators, and piping.

The reactor vessel has an over-all height of 33 ft., with a cylindrical section with an internal diameter of about 9 ft. with a nominal wall thickness of 8½ in. The total estimated dry weight of the reactor vessel is 250 tons. The vessel is formed of carbon steel plates and forgings with stainless steel cladding.

The steam generators are each rated at 263 x 10^6 B.T.U./hr. and provide 600 p.s.i. full-power steam pressure; this pressure

rises to 885 p.s.i. at no load. The secondary-side design pressure is 975 p.s.i. The primary side operating pressure is 2,000 p.s.i., with a design pressure of 2,500 p.s.i. Six and a half million pounds, or approximately one million gallons per hour of primary cooling water passes through the tubes, entering at a temperature of 542°F and leaving at 508°F. Two of these units are entirely of stainless steel construction and are of a straight tube, fixed-tube sheet design. They are 36 ft. long and 43 in. diameter.

The other two units are of a return bend of U-tube type. The over-all length is 28 ft., and the diameter is 39 in.

The active portion of the reactor core is in the form of a right circular cylinder 6 ft. in mean diameter and 6 ft. high. To minimize the amount of enriched U 235 used the core consists of some highly enriched seed and some blanket assemblies. The highly enriched, or seed assemblies, are located in a square annular region about 6 in. thick. The area inside and outside of the annulus is filled with natural uranium-oxide subassemblies. The seed assemblies contain a total of 52 kilograms of enriched U 235, and the blanket contains 12 tons of uranium in the form of UO_2. At the start of reactor life approximately 60% of the power will be produced in blanket assemblies and 40% in the seed assemblies.

The highly enriched fuel assemblies consist of zirconium-uranium alloy plates clad with Zircaloy-2. The zirconium-uranium alloy fuel sections of these plates are relatively corrosion-resistant and are also metallurgically compatible with the Zircaloy-2 cladding. This increases the probability of a good bond between the centre section and the clad. No imperfections in clad surfaces are expected. However, if there should be, this would cause only minor corrosion of the centre section, would not cause any mechanical deformation of the plates and would release only negligible quantities of fission products into the coolant stream.

On-off control of rods is initiated at plus or minus 3°F error, with a plus or minus 2°F deadband. As designed, the external temperature-control loop permits the negative temperature coefficient of reactivity to adjust power without motion of the rods for load changes of the order of 10 to 20% of full-power rating.

The turbine generator has a maximum capability of 100,000 kW and is a single cylinder 1,800 r.p.m. unit. The turbine has three points of extraction for steam. All of the steam leaves the turbine at the second extraction point and passes through a moisture separator and is returned to the turbine, the moisture being reduced from 11.6% to about 1%. The exhaust moisture will be about 13.2%. The cylinder barrel between blade rows is lined with stainless steel and all blades will be Stellite-faced, where the moisture content of the steam exceeds 6% and the blade tip speed exceeds 900 ft./sec. The gross turbine heat rate at 100,000 kW will be 11,385 B.T.U. per kWh.

Power Reactor Development Programme in the Netherlands *by Dr. J. J. Went (Kema Research Laboratories, Arnhem).*

The Netherlands power reactor development programme is based on liquid fuel reactors with wet or dry suspensions of uranium (thorium) oxides in heavy water or gas.

Although the intention is to develop a thermal breeder reactor with a slightly enriched ThO_2 suspension in heavy water, a start will be made with a moderately enriched UO_2 suspension in light water, as no enriched thorium is available at the moment. In the case of uranium, several oxides can be considered: UO_2; U_3O_8; UO_3, etc., and intermediate compositions are also possible. However UO_2 will be used.

The particle dimensions are restricted to an upper limit of about 12μ and a lower limit of about 3-5μ. The upper limit is equal to the mean range of the heavy fission products. If each particle is surrounded with a sufficient concentration, the fission products will leave the particles due to their kinetic energy resulting from the fission process. An automatic separation of poisoning fission products and the fissile or fertile material is obtained. To reduce the adsorption on the surface of the suspension particles, particles larger than 3μ are used and the particles are sintered at 1,700°C to make them completely dense.

Although the suspension reactor will demonstrate the amount of water decomposition the possibility of large formation of a detonating gas mixture must be considered. As soon as the gas mixture is separated from the suspension and before the catalytic recombination of its mixture occurs it is diluted with such an amount of hydrogen (or deuterium) that detonation is impossible. The same excess amount of hydrogen is necessary to keep the uranium oxide in the reduced state of UO_2.

Status of Nuclear Power Technology *by W. K. Davis (Director, Division of Reactor Development, U.S.A.E.C.).*

Economic nuclear power is not yet here except, perhaps, for very special circumstances, but it does seem quite possible and feasible even in the United States.

Much has already been accomplished in the basic fields of physics, chemistry, metallurgy, and engineering. In fact, sufficient knowledge has been gained to proceed with the design, construction and operation of several different types of reactor systems. Major advancements in technology will be required, however, before competitive costs can be achieved. Operational experience with both pilot and prototype nuclear power plants is needed in order to realistically assess the relative economic importance of the many technical factors involved. Such a programme is a long range one and several years will be required for achieving even the early goals both because of the technical difficulties and because of the time required for the first plants to be built and operated.

Utilization of the Heat from Reactors *by P. Chambadal and J. P. Roux (Head of Thermal Research Division, Department of Electrical Research, Electricité de France, Joint-director of the South region of Nuclear Equipment, Electricité de France).*

Nuclear energy recovery consists in producing electrical power at the expense of heat available in the cooling medium leaving the reactor. In the present state of nuclear engineering, the temperature of this medium cannot exceed some limit which is comparatively low. For this reason the nuclear energy can be recovered only by using steam as working medium. This energy can be recovered alone, or in combination with heat produced by burning a fuel. On the other hand the heat of the cooling medium can be transferred to water remaining in liquid state, or to boiling water (which is converted into saturated or superheated steam). Hence the nuclear energy recovery can follow many schemes which are investigated in this paper.

Two of these schemes have been applied to nuclear plants which are now under construction in France. In one of the plants (G_1) the reactor core contains natural uranium and has an open-cycle cooling system; the cooling medium is air under atmospheric pressure. The heat recovery system consists of a water-heater and of three flash boilers in series generating steam for a 5,750 kW turbine. Two other plants, G_2 and G_3, which are identical, consist of natural uranium reactors and have a closed-cycle cooling system; the cooling medium is CO_2 under an average pressure of 214 p.s.i. Each of them will generate about 28,000 kW electrical power (auxiliaries included).

AMERICAN NUCLEAR SOCIETY

The American Nuclear Society held its second Annual Conference in Chicago on June 6-8 when over 1,000 delegates were able to choose from amongst 180 papers delivered in 23 technical sessions. Although the majority of papers were contributed by staff from the National Laboratories there were a significant number from the larger industrial organizations. The general topic groups included Reactor Kinetics, Reactor Engineering, Chemistry, Fuel Technology, Biomedicine, Theoretical and Experimental Techniques and two sessions to highlight the current stakes of some of the more interesting power and research reactor developments. Of necessity, when such a large number of papers are to be read, the time allotted to each is small, perhaps 15-20 minutes and in the absence of printed papers much of the valuable detail is lost to the audience.

In a survey paper Mr. James A. Lane of the O.R.N.L. showed how rapidly the world reactor construction programme is now proceeding. He summarized this as follows:

	1955		1960	
	U.S.	*All others*	*U.S.*	*All others*
Research and test reactors ...	22	15	54*	50*
Power reactors and power prototypes	7	1	37	31
Total	29	16	91	81

* Estimated.

In a more detailed breakdown of research reactor types it was evident that the numbers based on the M T R type fuel elements almost monopolized the forward picture and that neither the work

horse of the old research reactor programme—the natural uranium graphite reactor—nor the water boiler were now being widely contemplated. The water boiler has now been shown to have some difficulties associated with the precipitation of uranium by excess peroxide formation at fluxes greater than 3 x 10^{12} n/cm^2-sec. in a non-pressurized system. His analysis of power reactor types showed that nearly every likely combination of moderator and coolant was now being tried either in the U.S.A. or the U.K. or U.S.S.R. power programmes. He drew attention to the fact that the U.S.S.R. power reactor programme as recently amplified by Igor Kurchatov at Harwell may amount to 2,000 MW electrical capacity by 1960 and that of the U.K. to 1,000 MW by the same date, whilst the reactor programme of the U.S. appears to lag behind these at 900 MW by 1960. However, he concluded that the more diversified approach to be seen in the demonstration programme of the A.E.C., the reactors to be jointly financed by the A.E.C. and industry, by the A.E.C. and the utilities and by industry alone represent a guarantee that when nuclear power costs become competitive with conventional power costs in the U.S.A. they will be in a position to expand rapidly on a broad front.

Noteworthy technical contributions of the year included the discovery of a copper solution catalyst which can be used to completely suppress gas production in a homogeneous reactor and the use of zirconium inhibitors to control mass transfer in a bismuth-uranium type reactor.

Three of the reactors in the A.E.C. power demonstration programme were reported in an advanced stage of construction, the experimental boiling water reactor at Argonne is due to operate in mid-1957, the larger Westinghouse pressurized water reactor at Shippingport will be complete towards the end of 1957 and the homogeneous reactor test at Oak Ridge is complete and is expected to go critical in October 1956. The experimental breeder reactor II is still in the design stage but a full-scale model of the large sodium tank in which the reactor core, circulating pumps and fuel rod handling and storage arrangements are immersed has been operated most successfully for some nine months and has given much confidence in this most original design feature.

A brief description was given of the more recently announced Organic Moderated Reactor Experiment (OMRE) which is to be built by N.A.A. at the V.R.T.S. in Idaho for completion in 1957. This will be a 16-MW reactor using diphenyl at 300 p.s.i. with inlet and outlet temperatures of 500° and 700°F. While the virtue of the organic moderator is its low vapour pressure at high temperatures and its compatibility with common structural materials at the working temperatures, its main disadvantage is the rate of chemical breakdown under temperature and irradiation. These properties have been extensively studied in reactor irradiation experiments but the proportion of dissociated material which can be tolerated in a reactor circuit and hence the rate of purification and make-up can only be evaluated in a reactor experiment.

Also discussed was the Liquid Metal Fuelled Reactor experiment (L.M.F.R.) now to be built by Babcock and Wilcox in conjunction with the Brookhaven National Laboratory. Design of the experiment is still in a preliminary stage but it is suggested as a 5-MW reactor in which the Bi-U fuel (U as 700 p.p.m.) will be pumped through the core at 750°F in and 1,020°F out. The heat will be discharged to atmosphere via a secondary closed gas circuit thus providing double protection against leak in the Bi-U fuel system. The core, which is some 4 ft. 5 in. in diameter and 4 ft. 6 in. high with a graphite to fuel volume ratio of unity will contain seven kilograms of U^{235} whilst the total circuit hold-up will be 25 kg U^{235}. The central flux will be 7 x 10^{13} n/cm^2-sec.

A very interesting new development of the homogeneous reactor which may prove most suitable for small mobile or package power plants was described by the Los Alamos Laboratory with reference to their power reactor experiments LAPRE 1 and LAPRE 2. Both these reactors employ aqueous uranium phosphate at high concentration (4 mol. and 17 mol. respectively). No catalyst is required for the recombination of radiolytic gases and with increasing fuel concentration the vapour pressure falls to less than 100 p.s.i. at 800°F. The solution is however very corrosive and all internal parts have to be gold plated. The design requires no transfer of solution for control purposes after the vessel is initially filled. LAPRE 1 which employs a self-contained pump to circulate the fuel through a heat exchanger is already in operation. It is expected to generate up to 2 MW. LAPRE 2 is a very simple system with no moving parts, the heat exchange to the secondary circuit within the core vessel being by natural convection. This unit is expected to be in operation in September and will run at 1,300 kW.

SPERT Experiment

Some of the experiments were described which have already been done on SPERT 1 (Special Power Excursion Reactor Test), which is the first of the very comprehensive series of these test facilities—SPERT 1-5 in the heterogeneous reactor series and KEWR 1-3 in the homogeneous reactor series—recently instigated by the A.E.C. as part of its reactor safety evaluation programme.

The SPERT 1 experiments are conducted in a non-pressurized MTR-type core and are similar to the pioneer Borax experiments reported at the Geneva conference, but will eventually cover a wider range of variables.

Most interesting moving pictures were shown of successive excursions (at 1/5 speed and in colour). The time and intensity of the power excursion could be estimated by the now familiar but impressive Cerenkov radiation, while the shut down mechanism of steam formation could be followed by the disruption of the water surface above the core.

Research Reactors

The 200 MW Canadian research reactor NRU was reported due for completion by the end of 1956 and details of its wide range of physics and engineering research facilities were given.

Westinghouse reported that, in search of higher and higher fluxes, their privately owned test reactor which was initially contemplated at 5-10 MW is now being built at 40 MW with eventual 60 MW operation in mind. While this reactor is in many respects similar to MTR and ETR it is proposed to use circular fuel elements employing a multiple annular arrangement of aluminium clad Al-U alloy fuel tubes. The central hole will provide a useful irradiation volume for small samples. In connection with the use of this reactor was a report on the problem of the design of the pressure-containing tube for hot loop experiments at, say, 2,000 p.s.i. and 4 x 10^{14} n/cm^2-sec. The radiation induced heating in the tube wall of 10 watts/gm or more introduces an additional thermal stress to be superimposed on the pressure stress and results in an optimum wall thickness at which minimum total stress results. This total stress may however be so high as to set very difficult problems in choice of material.

In conclusion the conference was treated to a most fascinating talk by Dr. Edward Teller, professor of physics at the University of California, on controlled thermo-nuclear power. With great artistry he simplified for engineers, under-lying principles, made the intriguing suggestion that the direct transformation of fusion energy into electrical power was a not impossible result of the processes described and concluded by stating his conviction that controlled thermo-nuclear power would be achieved but within what time scale it was impossible to predict at this stage.

"Die Atomwirtschaft"

A number of new journals on various aspects of atomic energy developments are appearing all over the world. Concentrating on the economic and business aspects, *Die Atomwirtschaft*, a monthly publication, was launched in Germany at the beginning of this year. Its aim is to present developments in nuclear engineering as they affect the investor and political relations, but specific technical information is not neglected. The following is a review of the articles appearing in the June issue which typifies the usual balance of contents:

"The German Federal Republic and International Collaboration in the Atomic Energy Field." By Bundesminister Franz Josef Strauss.

"The Insurance of Atomic Risks." Present position of these problems in Germany. By Dr. Rolf Stuttgart.

"Switzerland furthers Atomic Economy." By Dr. Paul Eisenring.

"Professional Education—but no Training of Specialists." By Dr. Karl Hecht.

"The Application of Radio-isotopes for Non-destructive Material Testing in the Oil Industry." By F. Gottfeld.

The journal is published by Handelsblatt G.m.b.H., Dusseldorf, the editor is Herr Wolfgang D. Muller and the journal is available in this country through their agents Messrs. F. C. Urbach, 63 Lancaster Grove, London, N.W.3, at a subscription rate of £3 12s. 0d. per year.

Processes and Equipment

Stabilized Plate Glass

Ceria-stabilized lead glass plate in sizes from 12 in. to 36 in. square is now being made by Pilkington Brothers Ltd., St. Helens, Lancashire. The limitations imposed by restricted window space create a problem in nuclear research so that, although extreme thickness is necessary for some operations, the relative thinness and larger size of the new plate glass will generally simplify remote control operations. With a 0.38 lead equivalent, the glass has a density of 4.3 gm per c.c.

Periscopes

Bodson periscopes are intended for use in industrial installations where normal visual examination of objects or phenomena is impossible owing either to their situation or attendant dangers. For nuclear applications they can be made of stainless steel with cerium-stabilized glass lenses.

The standard tube diameter is approximately 1.2 in., the maximum total length permissible for efficient results being 25 ft., and a variety of bends, with suitable prisms, can be introduced. The field of view is normally 45°-50°, but magnifications up to 8 times are possible if the angle of view is kept to 6°.

The objective heads can be made water or air tight, and the periscopes can be used with photographic apparatus. To increase the operator's field of view a scanning prism can be used, either turning within the objective tube or arranged to move towards or away from the objective. The use of standardized prism boxes and lens tubes makes different layouts readily possible.

The periscopes are made by J. Bodson et Fils, 14 Rue Denis-Papin, Puteaux (Seine), France. The sole U.K. agents are P. W. Allen and Co., 253 Liverpool Road, London, N.1.

New Filter Material

Knitted mesh for use in air filters, electronic shields, vaporizing sponges, demisters and so on is being made by Knitted Mesh Manufacturing Co., 36 Victoria Street, London, S.W.1, in a variety of materials—both metal and plastics—gauges, and widths. Knitmesh is stocking-knitted, has both a large surface area and a high percentage of free space, is light in weight in relation to its volume, and can be compressed to any desired shape whilst retaining all its properties, including resilience. It is available in fine, medium or coarse mesh with round or laminated section.

Radiographic Materials

In spite of the superior definition of a really fine grain X-ray emulsion, the inherent lack of speed tends to limit the usefulness of this type of film for radiography. Ilford Ltd., Ilford, Essex, have now, however, made certain changes in the emulsion of their Industrial F X-ray film which have increased the speed by about 50% without impairing its other characteristics.

Ilford PQX-1 is a concentrated liquid developer particularly suited to the requirements of industrial radiography. Incorporating the developing agent, Phenidone, it produces radiographs of high contrast, particularly in regions of greater density. It is supplied in 80-oz. bottles and requires dilution with only three parts of water to make two gallons of working-strength solution. A concentrated liquid replenisher is available.

Foam Fire-Fighting Unit

A trolley-mounted fire-fighting unit of 30-gallon capacity, capable of producing over 400 gallons of foam, is announced by the Pyrene Co. Ltd., 9 Grosvenor Gardens, London, S.W.1. It is particularly suitable for use where the water mains do not provide sufficient pressure for other forms of mechanical foam-making equipment.

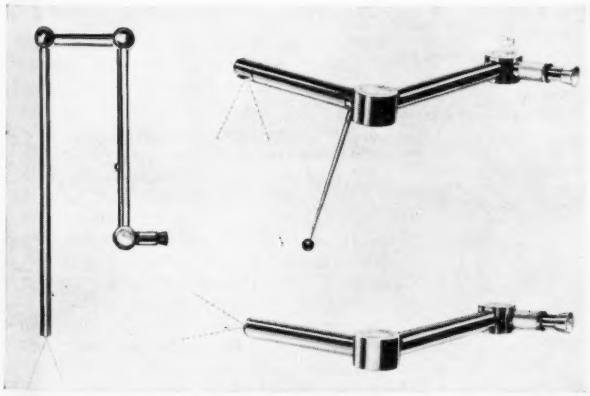
In this A.F. 30C unit, the 30-gallon tank contains a pre-mixed solution of water and Pyrene foam compound, a CO_2 cylinder being used to give the discharge pressure. Total discharge is completed in two minutes, and re-charging can be carried out on the spot in a few minutes.

The unit is mounted on a manœuvrable lightweight two-wheeled trolley. It weighs 670 lb. when charged, is 4 ft. 11 in. high and 2 ft. 7 in. wide.

Glass-Making Process

Multiform glass, originally developed in the U.S.A., is now being produced in Britain by James A. Jobling and Co. Ltd., Sunderland. The process of compressing specially treated glass powders in moulds and fusing to form a uniform opaque glass eliminates the difficulties of making small accurately-dimensioned articles on long production runs, control to 1/1000 in. being obtainable.

Production at Joblings is, for the moment, confined to television gun mount rods and to small beads which are being made for glass-to-metal seals used in the electronics industry.



(Below) Some of the different periscope arrangements possible with the Bodson lens tubes and prism boxes.

(Right) Handling thorium oxide at the thorium-processing plant in Sheffield operated for the A.E.A. by Thos. Firth and John Brown Ltd. The oxide is reduced to metallic thorium powder which is made into solid form under pressure and sintered at high temperature in vacuum furnaces. It is then forged into suitable shapes.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. each (including postage).

B.P. 748,264. Heat exchangers. A. Bell. To: Foster Wheeler Ltd.

The risk of direct contact between two heat exchanging fluids is minimized by surrounding the tubes through which one of the heat-exchanging fluids flows with a "barrier" fluid of a high coefficient of thermal conductivity enclosed in larger tubes surrounded by the other heat-exchanging fluid. Such a barrier fluid may be liquid or liquefied metal, mercury or low-melting quaternary alloys of bismuth such as Wood's and Rose's metals or any other substance of high thermal conductivity, which is fluid under conditions of use and which can safely be brought into contact with the heat exchanging fluids. The barrier fluid will circulate in a closed circuit and be maintained at a lower pressure than the heat exchanging fluids, so that a leak can be detected very quickly by the rising pressure in the closed barrier-fluid circuit.

B.P. 748,598. Method of converting ionic energy into electrical energy. To: Ohmart Corp. (U.S.A.).

If two chemically dissimilar electrodes, connected by a conductor, are exposed to radioactivity in the presence of an ionizable gas, then current flows through the connecting circuit from one electrode to the other. The same current effect is obtained if the electrodes are immersed in an ion plasma, however created. A "cell" for converting ionic energy into electrical energy consists of two dissimilar electrodes in an envelope containing the electrodes and a gas. The cell is calibrated by measuring the time taken to reach some predetermined fraction of its characteristic (full) voltage, by subjecting it to ionizing sources of known strength. If the cell is then exposed to an unknown source and again the time measured, then by comparing the lengths of time required to reach the same voltage, the intensity of the unknown ionizing medium can be determined.

B.P. 748,906. Gas discharge devices such as cold-cathode tubes. S. Jefferson. To: U.K. Atomic Energy Authority.

In order to maintain the discharge path in an ionized condition, a suitable gas is introduced into the gas discharge device such as krypton 85, or tritium. Tritium has the advantage that the beta energy is much lower and the useful ionization occurs within a few centimetres of the source. It is initially introduced in the form of a tritium-containing element preferably spot welded across the legs of a stirrup which is in turn welded to part of an electrode structure in the manner of a getter. The tritium is caused to be deposited over a selected region of the electrode structure or walls by providing a deposit of zirconium or tantalum over that region; for example, by spot welding a short length of such metal across the legs of the stirrup. The element may be a fine wire of highly purified zirconium impregnated with tritium and provided with a coating of copper, or it may be a ribbon of tungsten coated on one face with zirconium impregnated with tritium, or it may be a nickel tube filled with tritium.

B.P. 748,991. Exchange of deuterium between gaseous hydrogen and a liquid compound of hydrogen. To: U.K. Atomic Energy Authority (U.S.A.).

The object is to increase the concentration of deuterium in a liquid or gas containing both deuterium and hydrogen. It is possible to employ a countercurrent flow of hydrogen gas having a given concentration of deuterium and liquid water to enrich the water with deuterium whilst hydrogen moves from the water to the gas phase. However, this process takes a very long time to reach equilibrium, even when using highly active catalysts. It has been discovered that the rate at which the isotope exchange reaction between hydrogen and water proceeds may be enormously increased by causing the reaction to occur in the vapour phase at temperatures below the boiling point of water. The reaction can be carried rapidly to equilibrium at a relatively low temperature in the presence of catalysts of which platinum, palladium, and nickel are typical examples.

B.P. 749,064. Generation of nuclear power. W. M. Stratford. To: Texaco Development Corp. (U.S.A.).

The problems of producing nuclear power attendant to solid piles are eliminated when handling the fissionable materials in a fluidized, ebullient phase in heat transfer relation with a medium in a fluid phase. The energy from the material undergoing nuclear reactions is absorbed by the medium. The medium is conducted to an energy transfer zone, then recirculated through the fluidized fissionable particles for reheating. Fig 1 is a diagrammatic view of one form of an apparatus for carrying out the process. A reactor (11) has a fluidizing chamber (12) and a chamber of enlarged cross-section (13) to reduce the velocity of the particles. Cadmium or boron retarders (14) (horizontal) and (16) (vertical) are reciprocable by servo-motor mechanisms (15). The cyclone separator (17) is for the return of fines to chambers (12) and (13). The fluidizing medium with unseparated fines is passed through preheater (22) in intimate heat exchange with a coolant in tubes (23). There follows a further separator (26) on top of the preheater, another separator (28) of the ultrasonic or electrostatic type from which the fines are returned to the reactor by line (29), an isotope separation device (32), and a compressor (34). A coolant coil (38) is fed from a line (39) and discharges through (41) to a cooling, energy extraction zone shown as a fluid (gas) turbine (42) with a generator (43). The retarder mechanisms may be responsive to a temperature measuring device (47) and a radiation measuring device (51). The fissionable material, e.g., uranium oxide particles, is first charged to reactor (11). Graphite or beryllium particles may be added, also zirconium, magnesium or aluminium, characterized by a high rate of heat exchange and a low neutron capture cross-section. A sufficient quantity of fluidizing medium (air, hydrogen, deuterium, helium, also such gas mixtures) is then introduced by operating compressor (34). The mass will then appear as a violently boiling liquid closely contacting coils or tubes with excellent heat exchange results. The nuclear reactions are initiated automatically at a "critical" assemblage of fissionable and moderating materials. Sodium, potassium, bismuth, lead or tin in molten state (or water or diphenyl) can be used as coolant. Heavy water as coolant may also serve as moderator, as may helium or hydrogen.

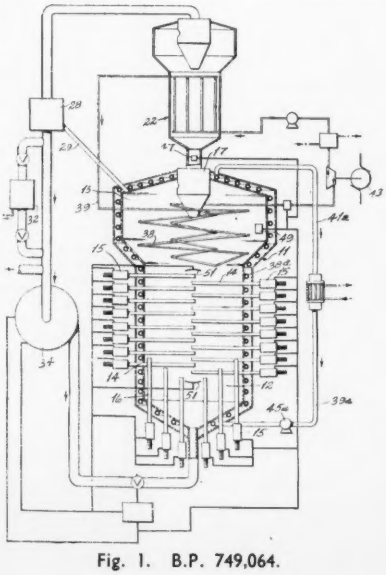


Fig. 1. B.P. 749,064.

B.P. 749,513. High intensity irradiation of fluids. W. J. Arrol. To: U.K. Atomic Energy Authority.

By using beta and gamma radiations certain chemical reactions may be influenced (polymerization; food sterilization). The sources proposed to date, fission products or cobalt-60 (gamma) and strontium-90 (beta) are hazardous. The invention envisages the use of krypton-85, which cannot be retained in living bodies, is practically only beta emitting, and for which the shielding problems are light. An apparatus for irradiating fluid with krypton-85 may be constructed like a heat exchanger with spaced 3-mm diameter nickel tubes of a wall thickness of 0.002 in. arranged as a regular hexagon lattice in a pressure vessel. No more than 60% of the radiation passing the walls is absorbed. Shielding is provided by a ½-in. lead jacket.